Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals During Marine Seismic Testing in the Northern Gulf of Mexico, April 2004

submitted by

Lamont-Doherty Earth Observatory
61 Route 9W, P.O. Box 1000
Palisades, NY 10964-8000

to

National Marine Fisheries Service
Office of Protected Resources
1315 East–West Hwy, Silver Spring, MD 20910-3282

Application Prepared by

LGL Ltd., environmental research associates
22 Fisher St., POB 280, King City, Ont. L7B 1A6

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SUMMARY

Lamont-Doherty Earth Observatory ("L-DEO"), a part of Columbia University, operates the oceanographic research vessel R/V *Maurice Ewing* (*Ewing*) under a cooperative agreement with the U.S. National Science Foundation (NSF), owner of that vessel. The *Ewing* is commonly used to conduct marine seismic surveys of an academic nature. L-DEO plans to obtain additional measurements of sounds from the *Ewing's* operating airgun arrays during a project in the northern Gulf of Mexico during 2004. L-DEO requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals (principally cetaceans) incidental to the acquisition of those acoustical measurements. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. § 1371 (a) (5). This work is planned to occur during April 2004 in small portions of the area between 24°N and 31°N and between 84°W and 92°W (Fig. 1).

The acoustical measurements will calibrate all acoustic sources that are commonly deployed from the *Ewing*. These measurements will be a follow-up to calibration work conducted in the Gulf of Mexico in late May/early June of 2003 under provisions of a previous IHA (LGL Ltd. 2003c). The 2003 measurements provided valuable data on the sounds from several of the acoustic sources, but are incomplete in various ways (L-DEO in prep.). Additional measurement data are needed to better understand the sound fields around the various acoustic sources during operations in different water depths. The data will be used to further verify and refine model-based estimates of "safety radii" for all configurations of airgun arrays that will be used during future seismic surveys to be conducted by L-DEO. The project will also provide corresponding information for sonars operated from the *Ewing.*

These operations will be in U.S. territorial waters and/or the U.S. Exclusive Economic Zone within the northern Gulf of Mexico. As presently scheduled, the acoustical measurements will be conducted for ~7 days during mid-April 2004. However, the exact dates may vary as project plans become more precise.

The measurements are to be done at deep, shallow, and intermediate sites, as was planned for 2003. (In 2003, data were in fact not acquired at the intermediate-depth site.) Exact study locations will be chosen to avoid areas of known cetacean concentrations, particularly where concentrations of sperm whales may be feeding or where concentrations of beaked whales have been observed. Thus, the actual measurement locations may be somewhat east or west of the nominal proposed location, depending on information about marine mammal distribution available at the time of the fieldwork.

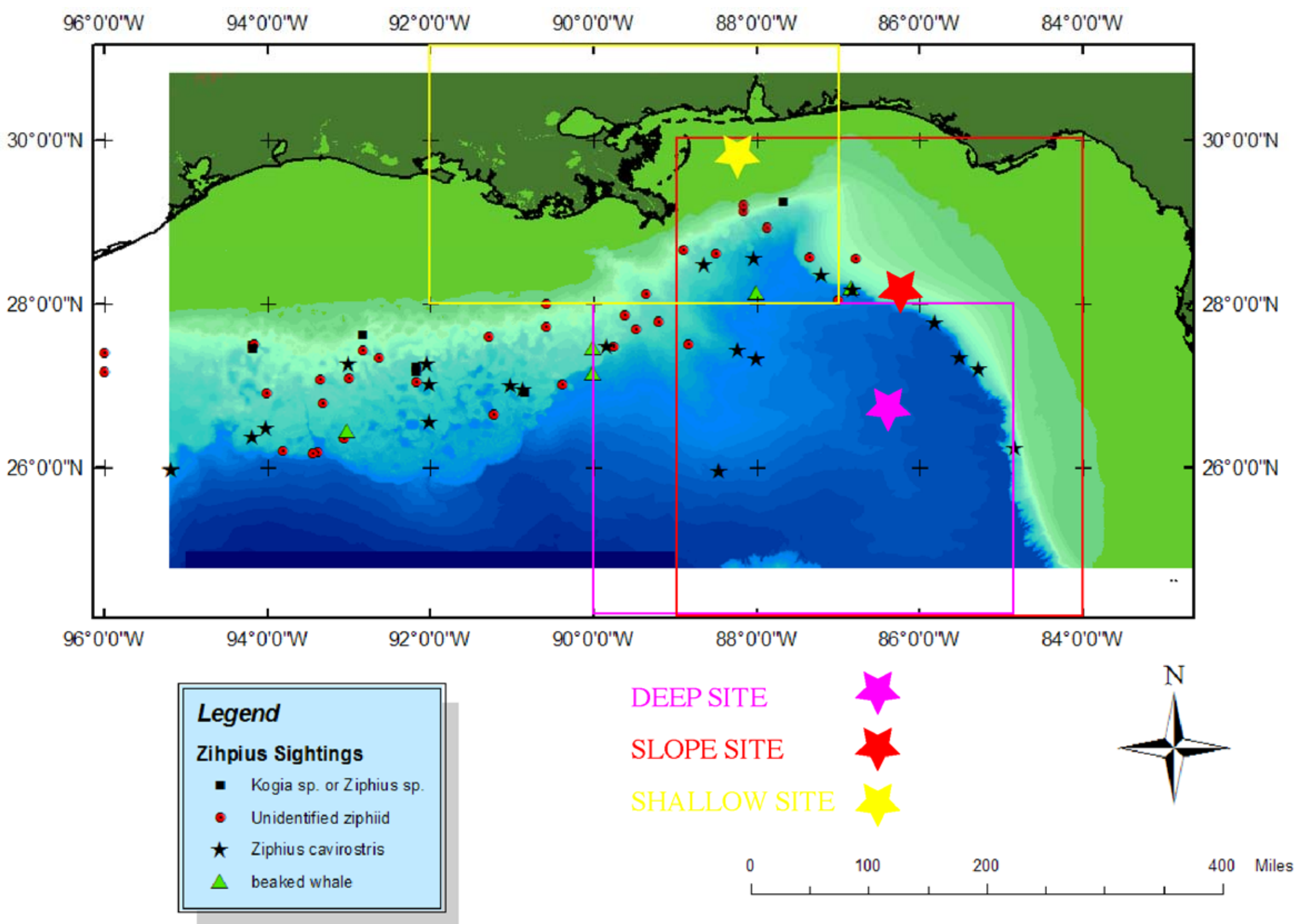


FIGURE 1. Nominal locations of the three planned study sites for the acoustical calibration study in the Gulf of Mexico during April 2004. Sighting locations of beaked whales are also depicted (from database collated by J. Ortega). Nominal study sites were selected as possible to avoid apparent concentrations of beaked whales. Specific locations may be adjusted in the field to avoid mammal concentrations evident at that time (see text).

Calibration measurements to be obtained during 2004 will differ from those obtained in 2003 as follows: ***(A)*** A bottom-moored buoy may be used if available, along with L-DEO's floating buoy. ***(B)*** Various improvements in the L-DEO buoy will be made. ***(C)*** Additional acoustic sources will be studied in 2004 as compared with 2003. ***(D)*** At each study site, each airgun array configuration will be operated along a separate line; this will ensure that airguns will be properly synchronized and that measurements for each airgun configuration will be available at closely-spaced intervals. ***(E)*** Shot lines at the shallow site will be lengthened to ensure that data are acquired at distances extending beyond the 160 dB re 1 μPa (rms) radius. ***(F)*** Only straight-line calibrations (bow to stern) are likely to be shot, providing data along the axis where received levels will be highest.

Numerous species of cetaceans, including one species (the sperm whale) listed under the U.S. Endangered Species Act (ESA), are present in the northern Gulf of Mexico. Pinnipeds and sirenians are not likely to be encountered. L-DEO is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activities on marine mammals present during conduct of the proposed research, and to document the nature and extent of any effects. The proposed 2004 monitoring and mitigation program is similar to the one proposed and implemented during the 2003 calibration cruise in the Gulf of Mexico (LGL Ltd. 2003a,b,c), with some modifications consistent with those adopted in consultation with the National Marine Fisheries Service (NMFS) during subsequent L-DEO seismic studies (LGL Ltd. 2003d,e,f,g).

The items required to be addressed pursuant to 50 C.F.R. § 216.104, "Submission of Requests" are set forth below. This includes descriptions of the specific operations to be conducted, the marine mammals occurring in the study area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor any behavioral effects of the operations on these marine mammals. No measures will be necessary to minimize conflicts between the proposed operation and subsistence hunting, because no hunting of marine mammals occurs in or near the area of the proposed activity.

I. Operations to be Conducted

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

Overview of the Activity

L-DEO, with grant support from NSF, plans to measure sound levels from each of the airgun arrays that will be used during their future seismic survey programs. This will include additional measurements of all five airgun configurations used in the 2003 Gulf of Mexico calibration study; plus measurements of sounds from an augmented 20-airgun array of larger total volume than that studied in 2003 (11,000 vs. 8600 in^3). Sounds from sonars operated from the *Ewing* will also be characterized. These measurements will be made in shallow, shelf slope, and deep waters in the Gulf of Mexico, probably during mid-April 2004. (Calibration measurements in 2003 were conducted only at one shallow-water and one deep-water site—LGL Ltd. 2003c.)

The primary purpose of these measurements is to verify and refine previous estimates of sound fields around the airgun arrays. The previous estimates were derived using L-DEO acoustical models and initial field measurements in 2003. Further verification of the output from these models and of the preliminary empirical data is needed to confirm the distances from the airguns at which sound levels diminish below various received levels. Such data are important in order to better define the distances within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at received levels exceeding established limits, e.g., 180 and 190 dB re 1 μPa (rms). The measurements will also further refine the estimates of distances at which the sounds diminish below other lower levels that may characterize the zone where disturbance is possible or likely, e.g., 160 or 170 dB re 1 μPa (rms). Preliminary results from 2003 indicate that, for a given source, these distances may be strongly dependent on water depth and (in deep water) on the depth of the receiver. Additional data are needed to confirm and better characterize these relationships for the sources tested in 2003, and to document the relationships for additional standard acoustic sources.

The data to be collected during this project can be used to continue to develop a better understanding of the impact of man-made acoustic sources on marine mammals. There is a paucity of calibrated data on the three-dimensional sound fields around such sources of underwater sound, and on the responses of marine mammals to known levels of sound from these sources. The planned project will obtain additional and refine existing calibrated measurements of the *Ewing's* acoustic sources across a broad range of frequencies from 1 Hz to 25 kHz. This will be done for various configurations of the *Ewing's* airgun array, including an augmented 20-airgun 11,000 in^3 array that was not operated during the 2003 calibration study but is planned for future use by L-DEO (LGL Ltd. 2003f). Calibration experiments will be conducted in shallow water, in the intermediate-depth shelf slope zone, and in deep water of the northern Gulf of Mexico to further quantify the differences in sound attenuation in relation to water depth. Once calibration measurements have been made, they will be used to refine the model for sound fields around the *Ewing*'s airgun arrays in varying geographical settings. This modeling will provide data needed to help minimize any potential risk to marine mammals during future seismic surveys.

The proposed sound measurements will involve one vessel, the *Ewing*. The *Ewing* will be self-contained, and the crew of the vessel will live aboard the vessel for the entire cruise. The primary calibration tool will be a specially adapted spar buoy with two hydrophones suspended at 18 m and 500 m depth. (However, at the shallow project site water depth is too shallow to deploy a hydrophone to 500 m, and both hydrophones will be at shallow depths.) In addition, at the slope and/or deep sites, a bottom-moored recording system, e.g., an Environmental Acoustic Recording System (EARS) buoy developed by the U.S. Navy and University of New Orleans, may be used to receive the sounds if it is available. That system, if used, would provide an independent source of data to complement and check those from the L-DEO spar buoy. Only the spar buoy was used during the 2003 Gulf of Mexico calibration study.

The *Ewing* will deploy the spar buoy and possibly a bottom-moored buoy, and it will then tow the various airgun arrays whose sounds are to be measured along straight lines passing close to the buoys. The *Ewing* will operate airgun arrays ranging in size from two GI guns (total volume 210 in^3) to 20 airguns with total volumes 8600 and 11,000 in^3. While towing a given airgun array at a speed of ~4 knots (7.4 km/hr), the guns will be fired at 20-sec intervals. The *Ewing* will approach the buoy(s) from ~10–15 km away, pass about 100 m to the side of the spar buoy, and continue for ~10–15 km past the spar buoy. Sound received at the spar buoy will be digitized and telemetered to the *Ewing*. Sound data received at the bottom-moored buoy (if it is used) will be recorded within that buoy and recovered later.

All planned data acquisition activities will be conducted by L-DEO scientists who have proposed the study. The scientists are headed by Dr. Maya Tolstoy of L-DEO at Columbia University.

During the 2004 Gulf of Mexico cruise, water depths in the study area will be ~30 m (100 ft) at the shallow site, ~1000–1500 m (3300–4920 ft) at the slope site, and ~3000 m (9840 ft) at the deep site. (During the 2003 calibration study, water depths were ~30 m [100 ft] at the one shallow-water site and ~3200 m [10,500ft] at the one deep-water site.)

Airgun operations will be conducted along a total of ~640 line-km. One survey line of length ~20–30 km will be located at each of the three sites, passing adjacent to the buoy(s). This line will be shot repeatedly (six times) in order to characterize sounds from each of the following six airgun array configurations: 2 GI guns; 6, 10, 12 and 20 airguns, plus an augmented 20-airgun array. This series of measurements will be done at each of the three sites. (During the 2003 study, only two lines were run at each site, one for the 2 GI guns and one for the 20-airgun array shooting, in a repeating sequence, 6, 10, 12 and all 20 of its airguns.) In addition, airguns will likely continue shooting while the *Ewing* turns between consecutive survey lines. The 640 line-km figure represents 400 km of planned surveys at the shallow (140 km), slope (140 km), and deep-water sites (120 km), as well as additional operations (240 km) associated with equipment testing, repeat coverage of any calibration run where initial data quality is sub-standard, firing during turns between lines, and possibly measurements of sounds from a small 3-gun array. To allow for these possible additional operations, § VI includes allowance for these potential contingencies. In comparison, the airguns were operated for a total of 322 line-km during the 2003 calibration study in the Gulf of Mexico (LGL Ltd. 2003c).

The six airgun configurations to be tested in 2004 will include all airgun configurations that are anticipated to be used during L-DEO's subsequent 2004 cruises, with the probable exception of a 3-airgun configuration. (During the 2003 study, data were obtained for five configurations, excluding the augmented 20-airgun array.) The 3-airgun configuration might be operated if the contingency-time is not all required for other purposes. The energy for the airgun array is compressed air supplied by compressors on board the source vessel. Airguns will be fired at intervals of 20 sec. In 2003, the 2 GI guns were shot at 30-sec intervals and the 6 to 20 airgun configurations were shot at 120-sec intervals. Analyses of the 2003 calibration data indicated that the airguns did not discharge well at the 120-sec rate. Also, the spacing of the shots from each specific gun configuration was undesirably wide, resulting in difficulties in characterizing the relationship between received levels and range, especially at the shorter distances where received levels change rapidly (L-DEO in prep.).

In addition to the airgun array, a multibeam bathymetric sonar (15.5 kHz hydrosweep) will be operated from the source vessel, most likely throughout the cruise, to measure water depths. A 12 kHz depth sounder and a 3.5 kHz sub-bottom profiler will also be operated during part of the cruise. Sounds produced by all three of these sonars will be specifically recorded via the L-DEO spar buoy as the vessel traverses a distance of several kilometers past the buoy. These recordings will be used to characterize the attenuation of these sounds with distance. Sonar sounds were not specifically measured during the 2003 Gulf of Mexico calibration study.

Vessel Specifications

The R/V *Maurice Ewing* will be used as the source vessel for the airgun sounds. It will also deploy and retrieve the spar buoy (and the bottom-moored buoy if it is used) that will receive the underwater sound data. The *Ewing* has a length of 70 m (230 ft), a beam of 14.1 m (46.3 ft), and a draft of 4.4 m (14.4 ft). The *Ewing* has four 1000 kW diesel generators that supply power to the ship. The ship is powered by four 800 hp electric motors that, in combination, drive a single 5-blade propeller in a Kort nozzle and a single-tunnel electric bow thruster rated at 500 hp. At the typical operation speed of 7.4–9.3 km/h (4–5 knots) during seismic acquisition, the shaft rotation speed is about 90 rpm. When not towing seismic survey gear, the *Ewing* cruises at 18.5–20.4 km/h (10–11 knots) and has a maximum speed of 25 km/h (13.5 knots). It has a normal operating range of about 31,500 km (17,000 n.mi.).

The *Ewing* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals before and during airgun operations. The characteristics of the *Ewing* that make it suitable for visual monitoring are described in § XI, MITIGATION MEASURES.

Other details of the *Ewing* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory of Columbia University
Flag:	United States of America
Date Built:	1983 (modified in 1990)
Gross Tonnage:	1978
Fathometers:	3.5 and 12 kHz hull mounted transducers; Furuno FGG80 Echosounder; Furuno FCU66 Echosounder Recorder
Bottom Mapping Equipment:	Atlas Hydrosweep DS-2, 15.5 kHz (details below)
Compressors for Air Guns:	LMF DC, capable of 1000 scfm at 2000 psi (scfm = standard cubic feet per minute)
Accommodation Capacity:	21 crew plus 3 technicians and 26 scientists

Airgun Array Descriptions

The airgun arrays to be used from the *Ewing* during the proposed program will consist of 2 GI guns and 20 Bolt airguns, with varying numbers of the 20 guns being operational at any given time.

- The two 105 in^3 GI guns will be towed 7.8 m apart side by side and 37 m behind the *Ewing*.
- During operations with 6 airguns from the standard 20-gun array, the operating airguns will range in chamber volume from 80 to 500 in^3. The six operating guns will be located within an (approximately) 9 x 9 m area behind the vessel (Fig. 2A).
- During operations with 10, 12, and 20 airguns from the standard 20-gun array, the operating airguns will range in volume from 80 to 850 in^3 (Fig. 2A). Chamber volumes of the airguns in the augmented 20-airgun array range from 80 to 875 in^3 (Fig. 2B). The airguns in each of the 10–20 gun arrays will be widely spaced in an approximate rectangle of dimensions 35 m across track by 9 m along track. The 10- and 12-gun arrays represent subsets of the standard 20-gun array.

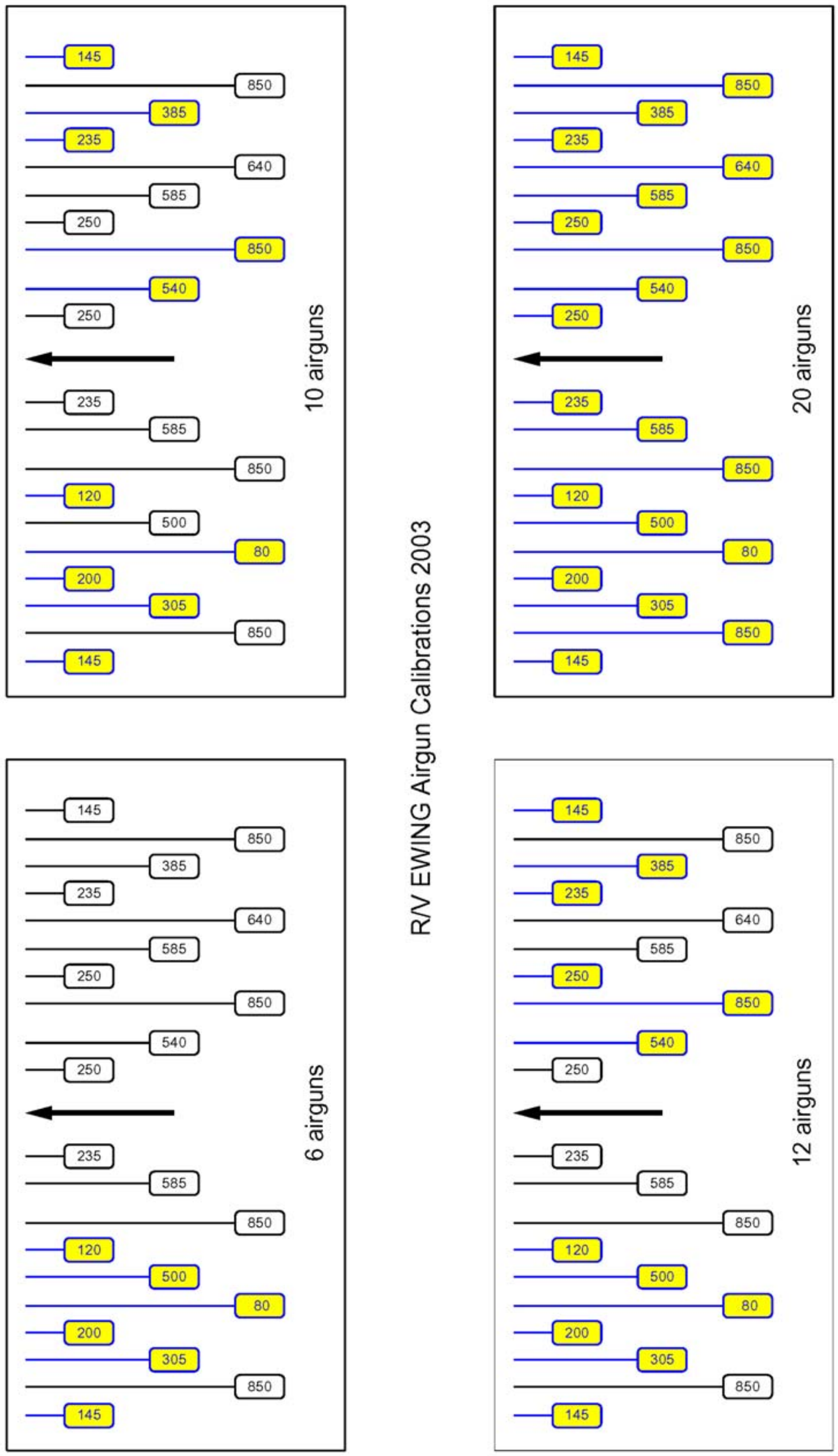


FIGURE 2A. The standard 20-gun array and the three subsets of that array that will be operated from the *Ewing* during measurements of seismic sounds in the Gulf of Mexico in April 2004.

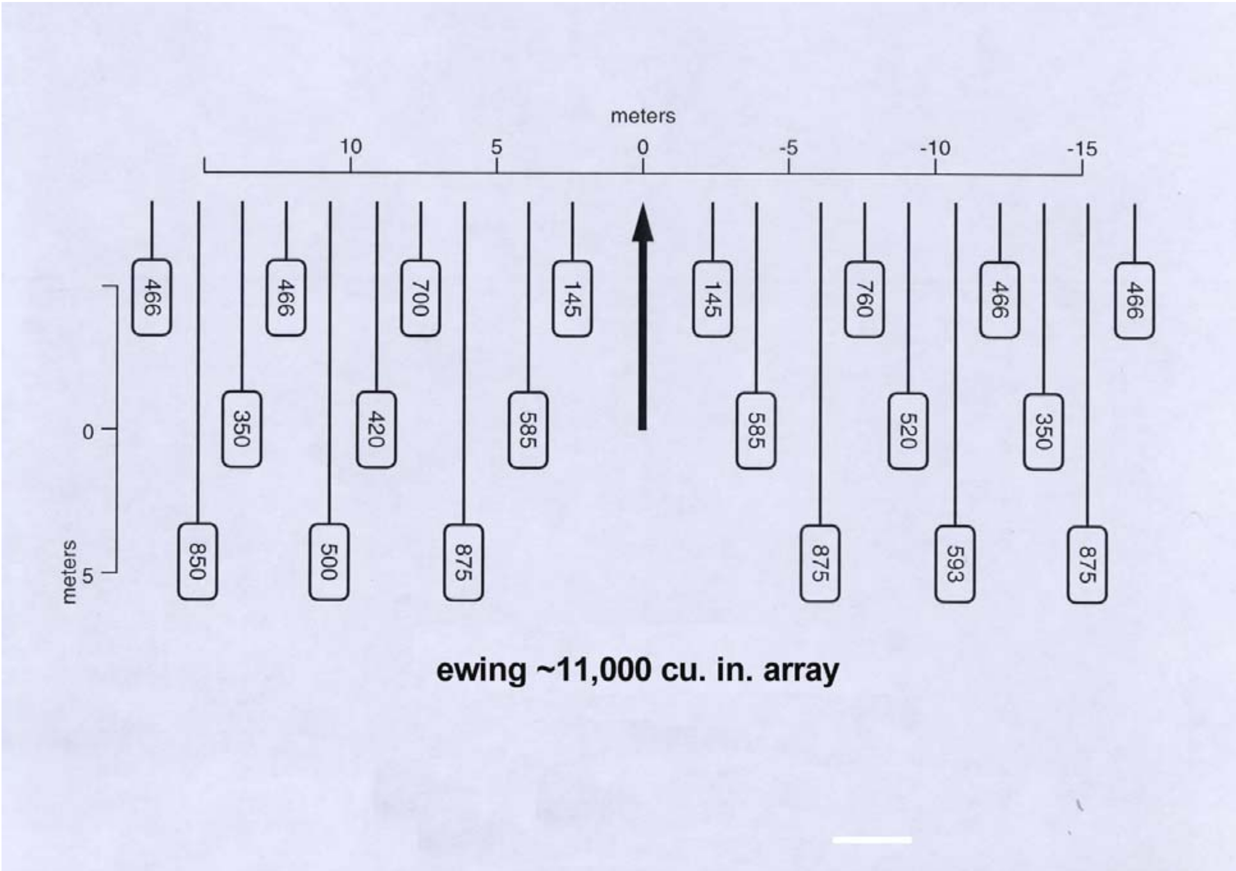
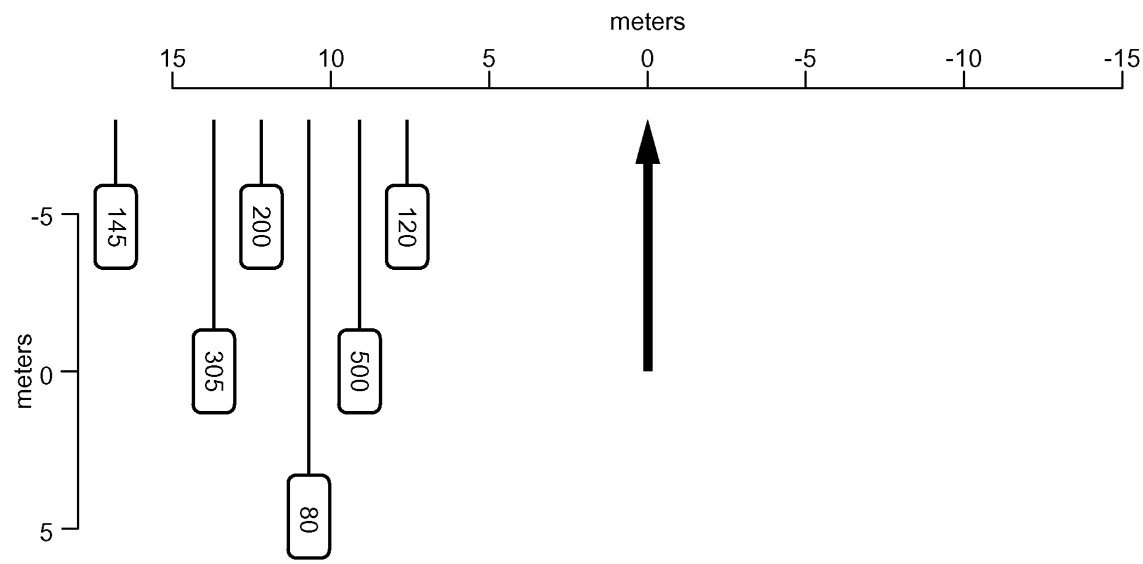


FIGURE 2B. The augmented 20-gun array that will be operated from the *Ewing* during measurements of seismic sounds in the Gulf of Mexico in April 2004.

The six combinations of airguns, including the 2 GI guns and 6, 10, 12 and all 20 of the 20 guns in the standard and augmented arrays will be fired separately on dedicated survey lines. Total airgun volumes for those six combinations will be 210, 1350, 3005, 3755, 8600, and 11,000 in^3, respectively. The standard and augmented 20-gun arrays and subsets of this array are shown in Figure 2A,B.

The airgun arrays that will be used during the acoustic measurements of seismic sounds are not necessarily identical to those that will be used during future studies because gun volumes and positions are selected to meet the specific objectives of each study. However, the subsets of the 20-gun arrays that will be used during the acoustic measurements were selected to closely match the arrays that will be used during future studies (see Fig. 3–6).

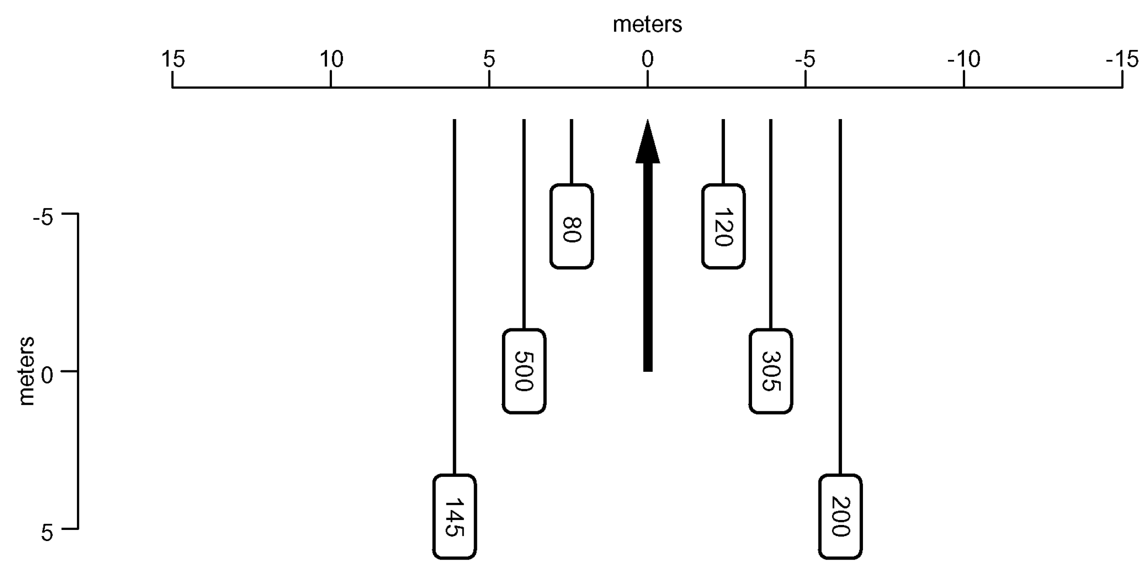
The characteristics of the various airgun arrays are tabulated below, including the nominal source levels. All source level estimates are for a filter bandwidth of approximately 0–250 Hz. Because the actual source is a distributed sound source (2 to 20 guns) rather than a single point source, the highest sound level measurable at any location in the water will be less than the nominal source level (Caldwell and Dragoset 2000). Also, because of the directional nature of the sound from an airgun array involving several airguns, the effective source level for sound propagating in near-horizontal directions will be substantially lower.



ewing_6gun_calibration.array

total volume 1350 cu. in.

14.2 bar-meters [243 dB] Peak, 31.4 b-m [250 dB] P-P



ewing_6gun_array

total volume 1350 cu. in.

14.2 bar-meters [243 dB] Peak, 31.4 b-m [250 dB] P-P

FIGURE 3. The 6-gun subset of the standard 20-gun array that will be used during measurements of seismic sounds and the 6-gun array that will be used during other studies conducted in 2004.

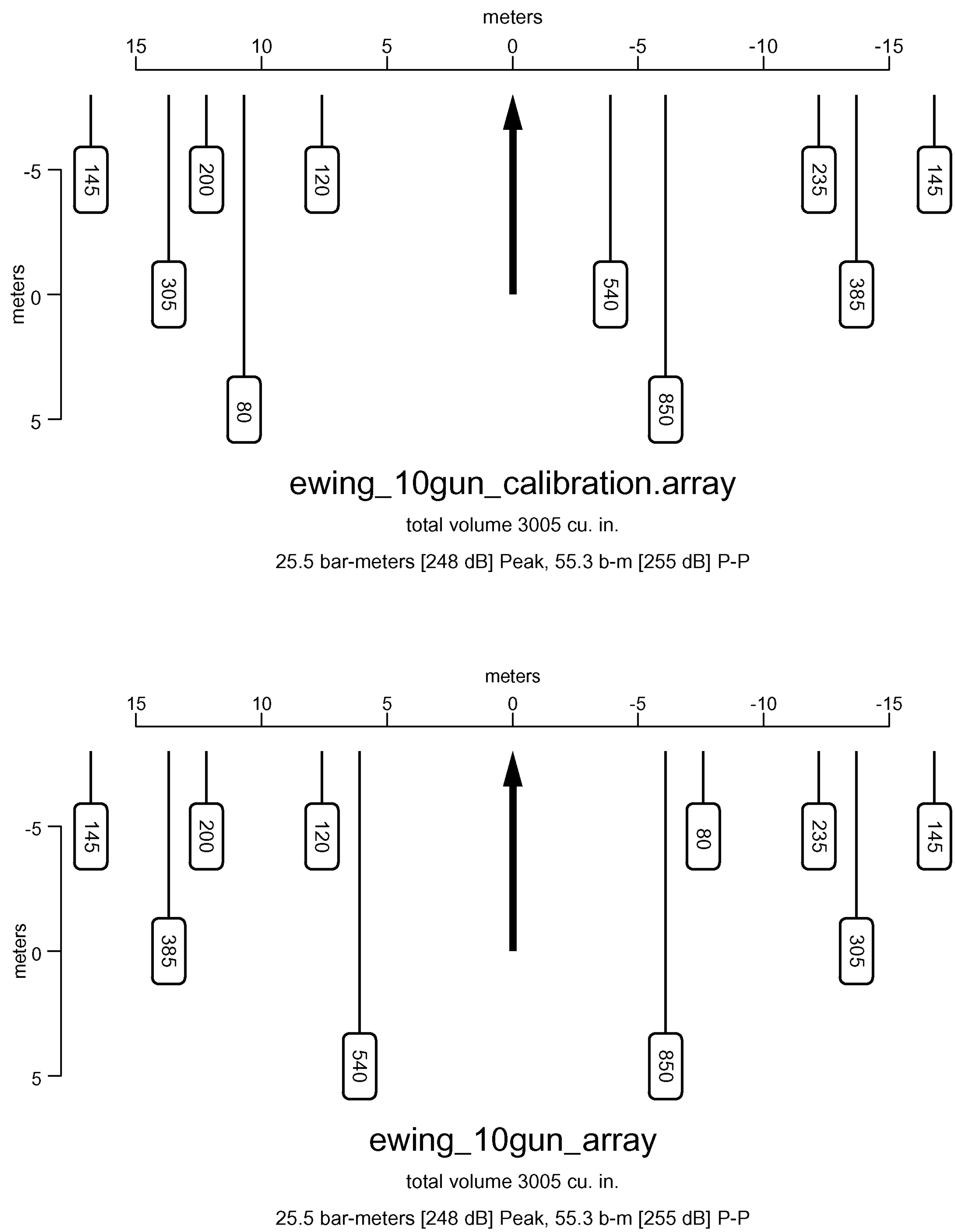
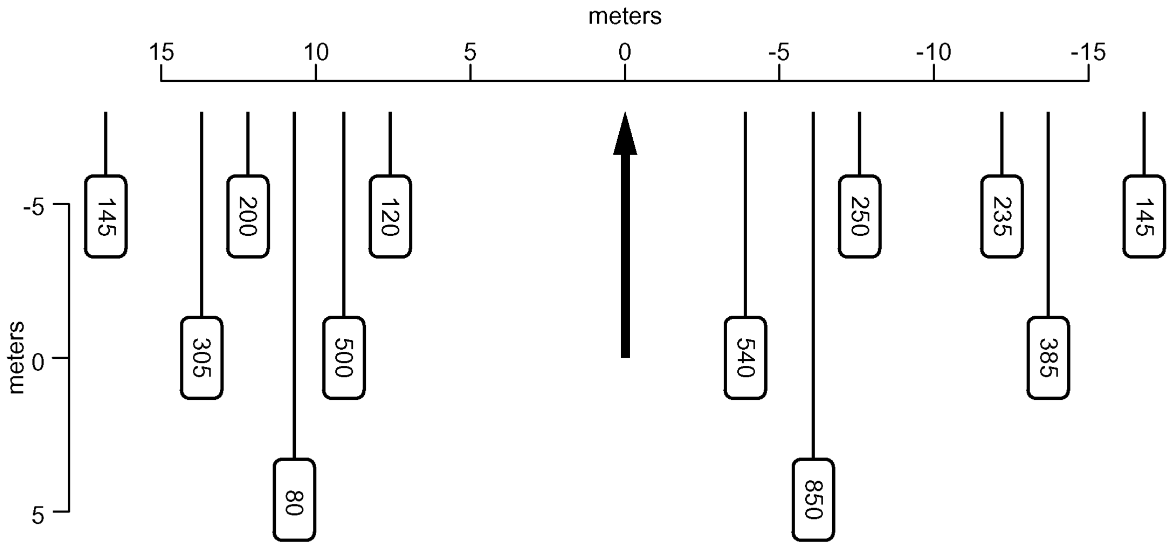


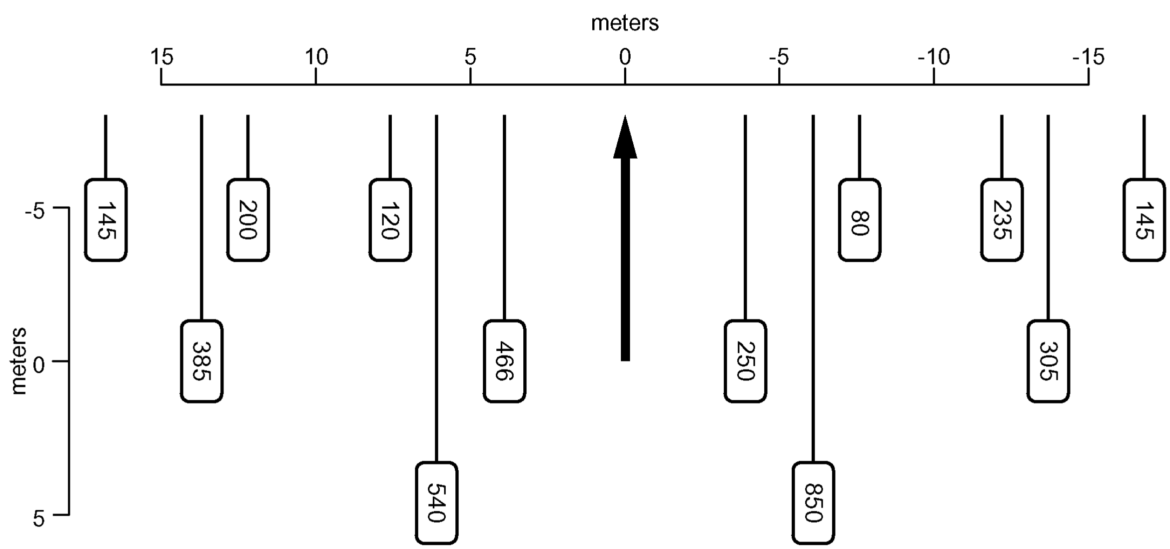
FIGURE 4. The 10-gun subset of the standard 20-gun array that will be used during measurements of seismic sounds and the 10-gun array that will be used during other studies conducted in 2004.



ewing_12gun_calibration.array

total volume 3755 cu. in.

31.3 bar-meters [250 dB] Peak, 68.2 b-m [257 dB] P-P

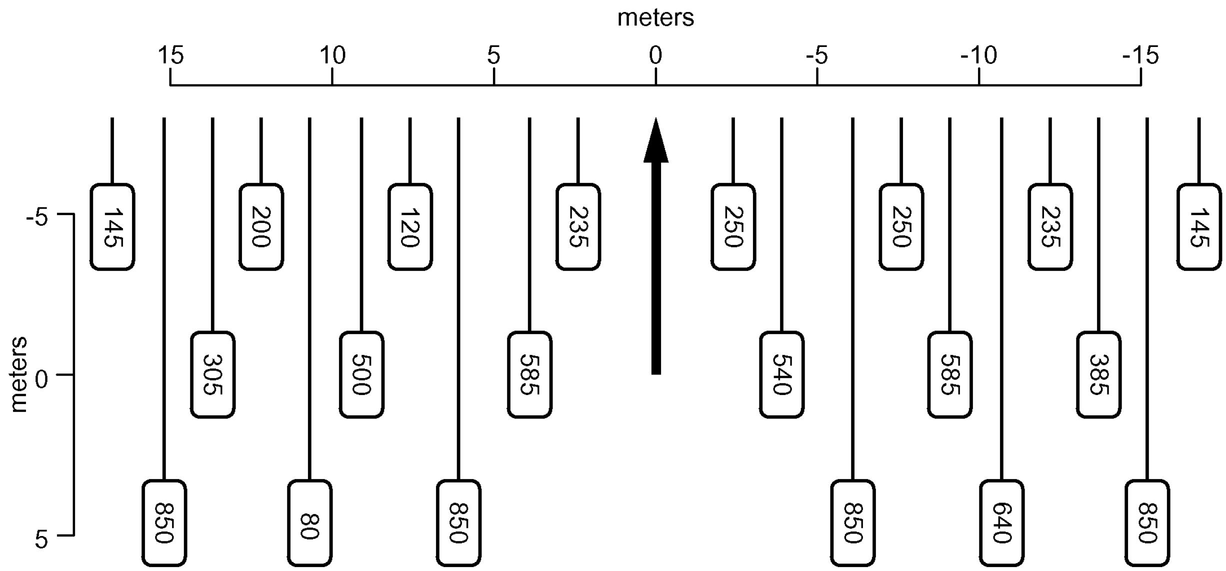


ewing_12gun_array

total volume 3721 cu. in.

31.2 bar-meters [250 dB] Peak, 68.2 b-m [257 dB] P-P

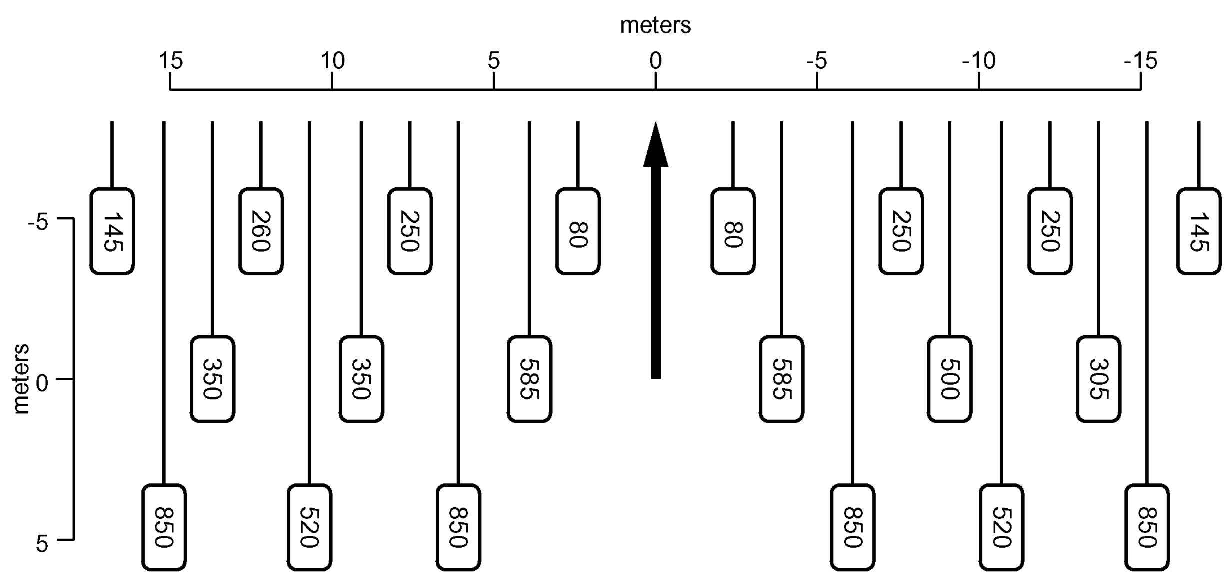
FIGURE 5. The 12-gun subset of the standard 20-gun array that will be used during measurements of seismic sounds and the 12-gun array that will be used during other studies conducted in 2004.



ewing_20gun_calibration.array

total volume 8600 cu. in.

57.9 bar-meters [255 dB] Peak, 123.4 b-m [262 dB] P-P



ewing_20gun_array

total volume 8575 cu. in.

57.7 bar-meters [255 dB] Peak, 123.7 b-m [262 dB] P-P

FIGURE 6. The standard 20-gun array that will be used during measurements of seismic sounds and the 20-gun array that will be used during other studies conducted in 2004.

Augmented 20-Airgun Array Specifications

Energy Source	Twenty 2000 psi 1500C-LL Bolt airguns, 145–875 in^3
Source output (downward)[1]	0-pk is 64 bar-m (256 dB re 1 μPa-m); pk-pk is 142 bar-m (263 dB)
Towing depth of energy source	9.0 m
Air discharge volume	Approx. 11,000 in^3
Dominant frequency components	0–188 Hz
Gun positions used	see Figure 2B
Gun volumes at each position (in^3)	see Figure 2B

Standard 20-Airgun Array Specifications

Energy Source	Twenty 2000 psi 1500C-LL Bolt airguns, 80–850 in^3
Source output (downward)	0-pk is 58 bar-m (255 dB re 1 μPa-m); pk-pk is 124 bar-m (262 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 8600 in^3
Dominant frequency components	0–188 Hz
Gun positions used	see Figures 2A, 6
Gun volumes at each position	see Figures 2A, 6

12-Airgun Array Specifications

Energy Source	Twelve 2000 psi 1500C-LL Bolt airguns, 80–850 in^3
Source output (downward)	0-pk is 31.3 bar-m (250 dB re 1 μPa-m); pk-pk is 68.2 bar-m (257 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 3755 in^3
Dominant frequency components	0–188 Hz
Gun positions used	see Figures 2A, 5
Gun volumes at each position (in^3)	see Figures 2A, 5

10-Airgun Array Specifications

Energy Source	Ten 2000 psi 1500C-LL Bolt airguns, 80–850 in^3
Source output (downward)	0-pk is 25 bar-m (248 dB re 1 μPa-m); pk-pk is 55 bar-m (255 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 3005 in^3
Dominant frequency components	0–188 Hz
Gun positions used	see Figures 2A, 4
Gun volumes at each position (in^3)	see Figures 2A, 4

6-Airgun Array Specifications

Energy Source	Six 2000 psi 1500C-LL Bolt airguns, 80–500 in^3
Source output (downward)	0-pk is 14.2 bar-m (243 dB re 1 μPa-m); pk-pk is 31.4 bar-m (250 dB)
Towing depth of energy source	7.5 m

[1] All source level estimates are for a filter bandwidth of approximately 0–250 Hz.

Air discharge volume	Approx. 1350 in^3
Dominant frequency components	0–188 Hz
Gun positions used	see Figures 2A, 3
Gun volumes at each position (in^3)	see Figures 2A, 3

2 GI Gun Specifications

Energy Source	Two GI airguns of 105 in^3 each
Source output (downward)	0-pk is 7.2 bar-m (229 dB re 1 μPa-m); pk-pk is 14.0 bar-m (236 dB)
Towing depth of energy source	6.0 m
Air discharge volume	Approx. 210 in^3
Dominant frequency components	0–188 Hz
Gun positions used	two side by side guns 7.8 m apart
Gun volumes at each position (in^3)	105, 105

For each of the six planned configurations of the airgun array, the sound pressure field has been modeled by L-DEO in relation to distance and direction from the airguns, and in relation to depth. Predicted received sound levels are depicted in Figures 7–12. Table 1 shows the maximum distances from those airgun arrays where sound levels of 190, 180, 170 and 160 dB re 1 μPa (rms) are predicted to be received. Here the rms (root-mean-square) pressure is an average over the pulse duration.

Preliminary calibration data for five of the six array configurations were obtained in 2003 from a shallow site (30 m) and a deep site (3200 m) within the northern Gulf of Mexico (L-DEO in prep.). Those data show that the actual received levels fore and aft of the ship tend to be lower than the predicted values in deep water, but higher than the predicted values in shallow water. The calibration measurements to be obtained during the planned 2004 program will provide more comprehensive data on the sound fields around the various airgun arrays, and on the maximum distances at which various received levels typically occur.

Airgun Operations

When operations with a 20-gun array (or a subset of those guns) commence after a period without airgun operations, the number of guns firing will be increased gradually or “ramped up”. This process is described as a “soft start” in some jurisdictions; see § XI, “MITIGATION MEASURES”. Operations will begin with the smallest gun in the array that is being used (80 in^3). Guns will be added in a sequence such that the source level of the array will increase in steps not exceeding 6 dB per 5-minute period over a total duration of ~14 min (6 gun array), 18–20 min (10–12 gun arrays) or 23–25 min (20-gun array).

When operations with the 2 GI guns commence after a period without airgun operations, no ramp up is planned because the total air discharge volume for these guns is small (210 in^3). However, two observers are required to monitor the area for 30 min prior to initiating operations with 2 GI guns as well as operations with larger arrays of airguns (see § XI, “MITIGATION MEASURES”).

During the calibration program, no streamer (hydrophone array) will be towed behind the source vessel. A spar buoy (and possibly a bottom-moored buoy) will receive the acoustic data from the various airgun arrays. The spar buoy will transfer the data via radio telemetry to the on-board processing system. If the bottom-moored buoy is used, it will record data aboard the buoy, for retrieval at the end of the measurement sequence at a given site.

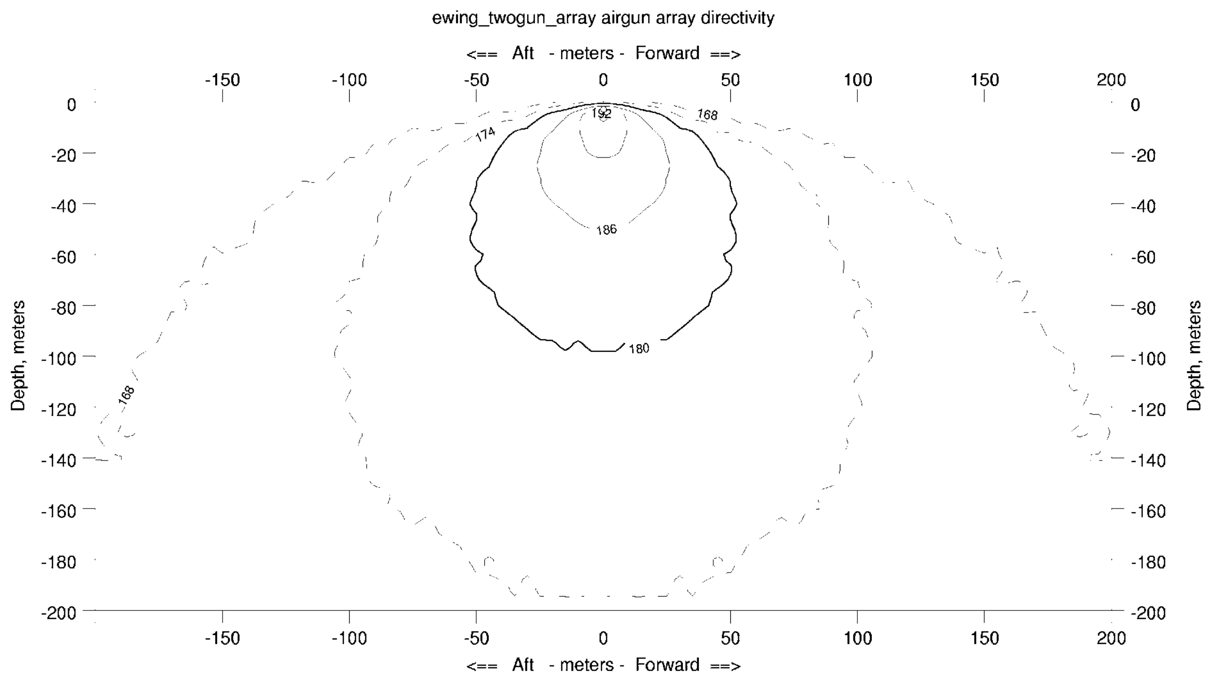


FIGURE 7. Modeled received sound levels from the 2 GI guns that will be used during the seismic calibration program in the Gulf of Mexico and during L-DEO seismic surveys in 2004.

The shallow and deep-water sites are proposed to be shot 24 hr per day to maximize effective and economic use of the limited ship time. This will maximize the amount of calibration data collected. If airgun operations were constrained only to daylight hours, L-DEO would be unable to calibrate six airgun arrays in the time available for the 2004 survey. Operating airguns over 24-hr periods will also reduce the overall duration of airgun operations at the shallow and deep sites, thus reducing the span of time when marine mammals in those areas will be exposed to airgun sounds.

At the slope site, airgun operations will be limited to daylight hours (~12 hr/day) in order to improve the monitoring and mitigation measures applied at those sites. Beaked whales tend to be found more frequently in slope waters than shallow or deep waters in the Gulf of Mexico (Fig. 1; Davis and Fargion 1996; Davis et al. 2000). Visual monitoring is much more effective during daylight hours, so limiting airgun operations in slope waters to daylight hours will improve the ability to detect potential beaked whales in potentially sensitive slope areas. If concentrations of beaked whales are observed at the slope site just prior to or during the airgun operations there, those operations will be moved to another location along the slope based on recommendations by the lead marine mammal observer aboard the *Ewing.*

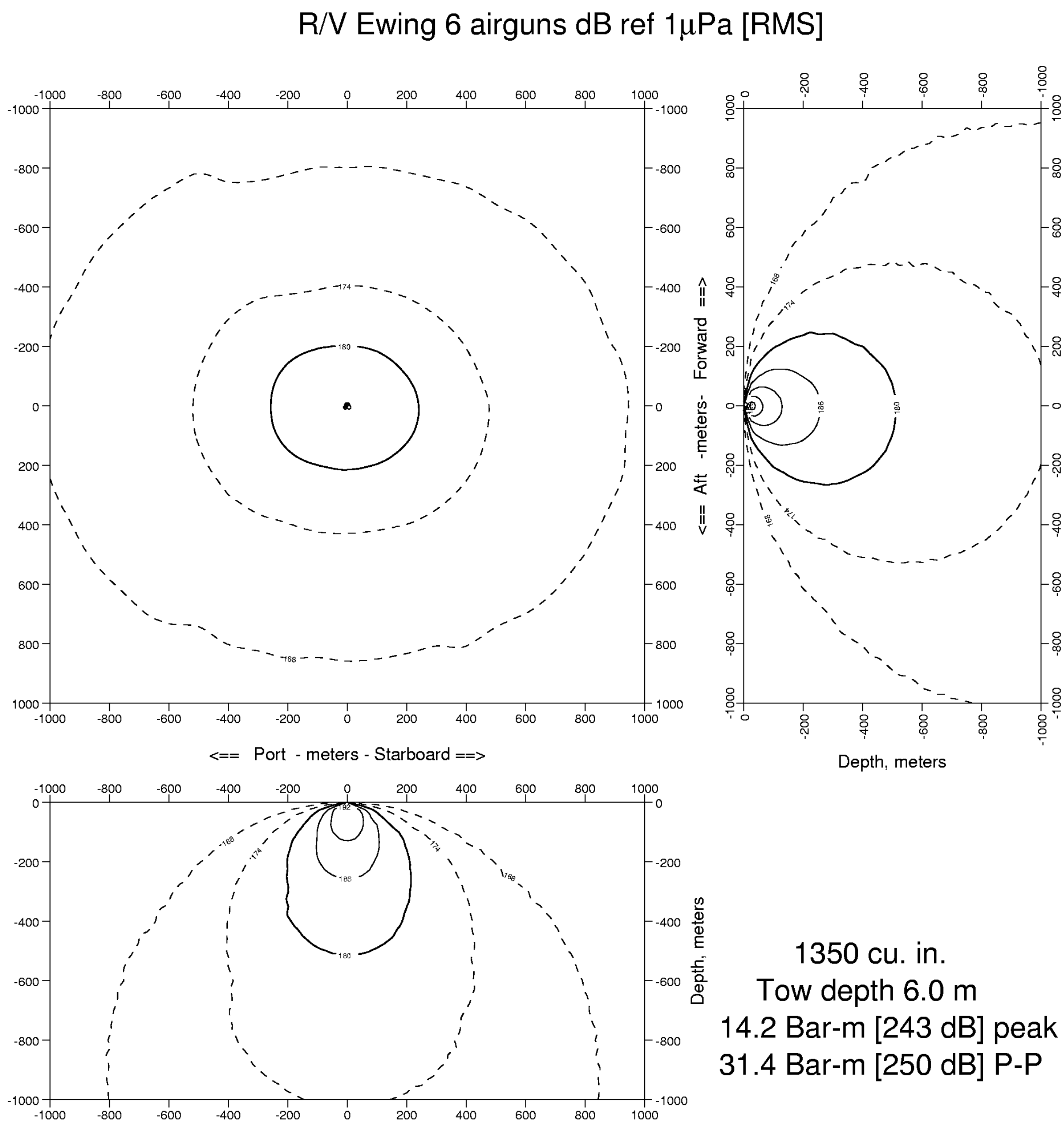


FIGURE 8. Modeled received sound levels from the 6-gun array that will be used during L-DEO seismic surveys in 2004. The received levels are almost identical for the array that will be used during sound measurements in the Gulf of Mexico.

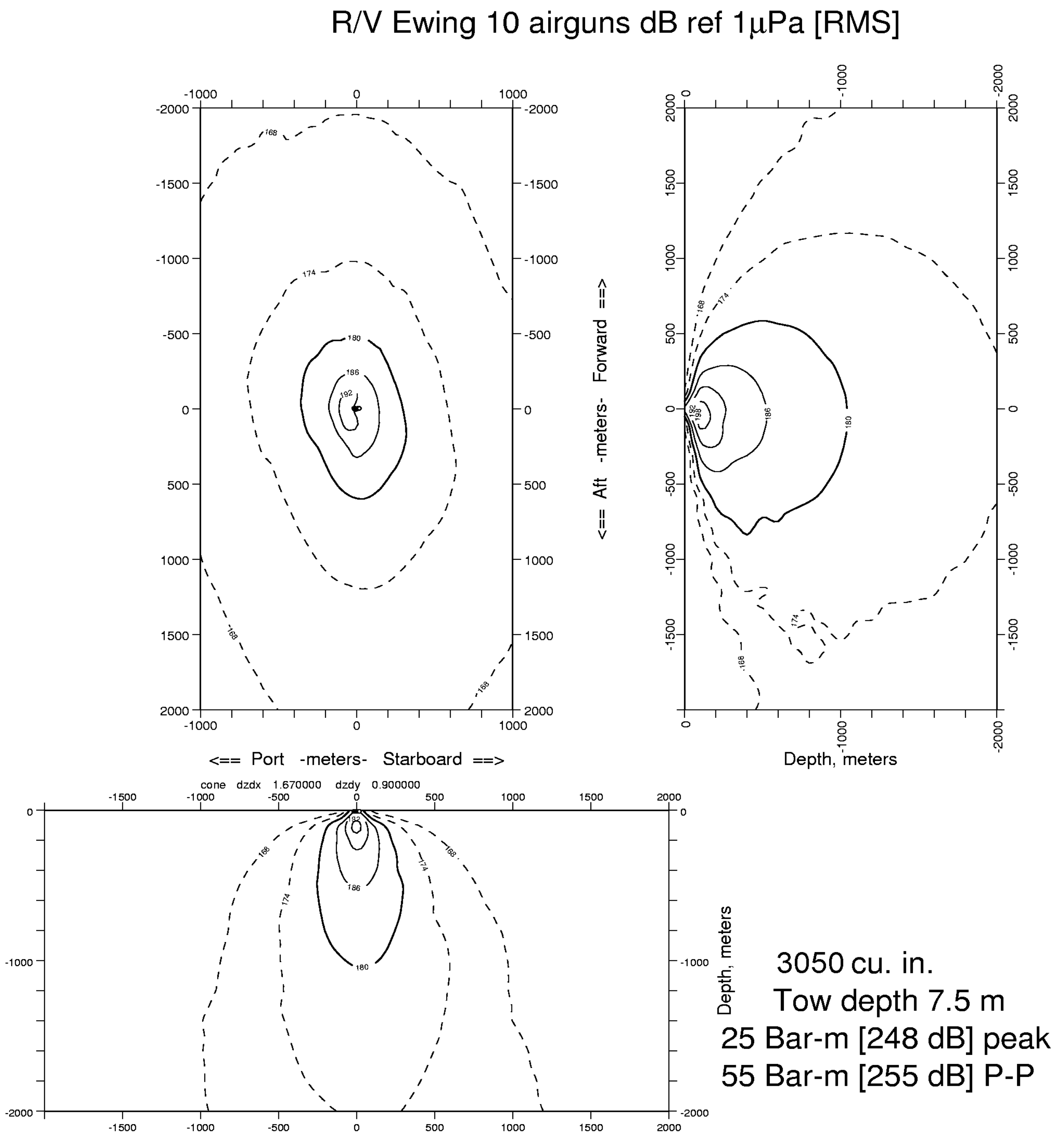


FIGURE 9. Modeled received sound levels from the 10-gun array that will be used during L-DEO seismic surveys in 2004.

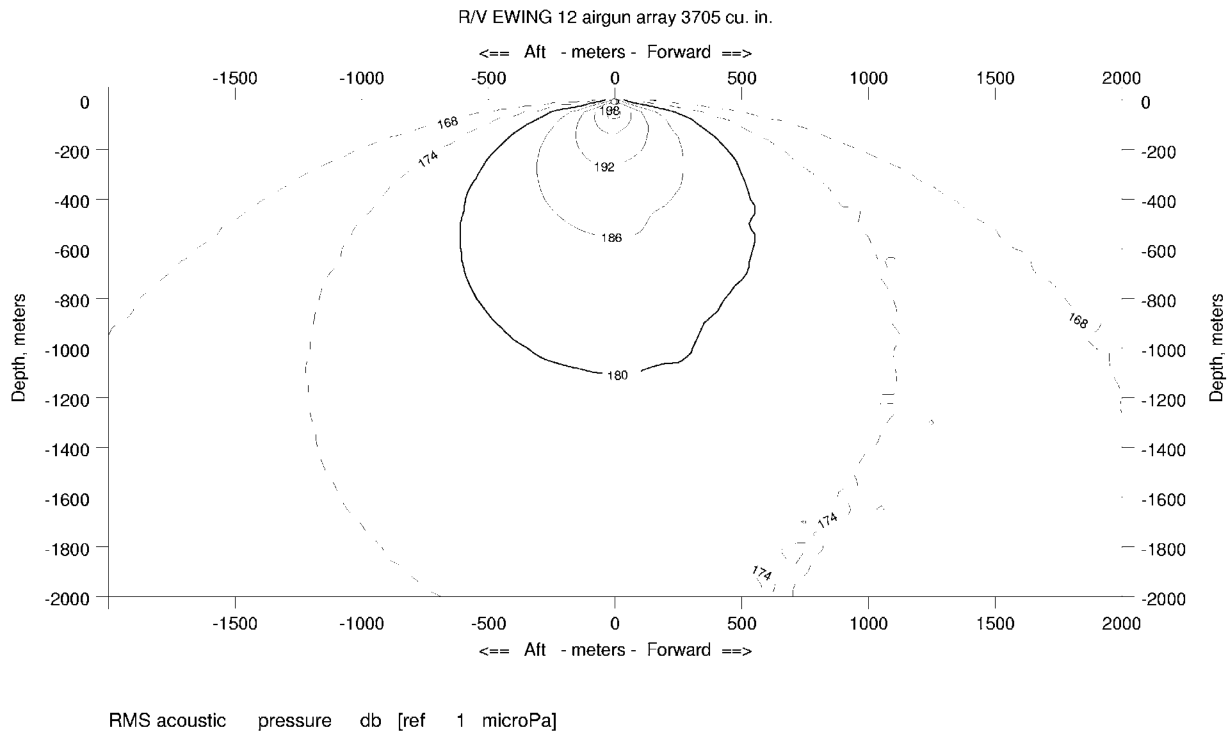


FIGURE 10. Modeled received sound levels from the 12-gun array that will be used during L-DEO seismic surveys in 2004.

Multibeam Sonar and Sub-bottom Profiler

Along with the airgun operations, three additional acoustical data acquisition systems will be operated during most or part of the cruise. The ocean floor will be mapped with an Atlas Hydrosweep DS-2 multibeam 15.5-kHz bathymetric sonar while the calibration is being done with the 2 GI guns and the 6- to 20-gun arrays. A 3.5- sub-bottom profiler will also be operated along with the multibeam sonar. The 3.5-kHz sound source is commonly operated from the *Ewing* simultaneous with the airgun array. The 12-kHz bathymetric sonar source is operated infrequently; the 15.5 kHz hydrosweep is generally used instead to record water depth under the ship. However, as part of the 2004 acoustic calibration study, sounds from each of these three sonars will be specifically measured over several line-km when the airguns are not operating. These measurements will provide data on the propagation of the sonar sounds away from the ship.

Atlas Hydrosweep

This 15-kHz sonar is mounted in the hull of the *Ewing*, and it operates in three modes, depending on the water depth. There is one shallow water mode and there are two deep-water modes: an Omni mode and a Rotational Directional Transmission mode (RDT mode). ***(1)*** When water depth is <400 m, the source output is 210 dB re 1 μPa·m rms and a single 1-millisecond pulse or "ping" per second is transmitted, with a beam width of 2.67 degrees fore-aft and 90 degrees athwartship. The beam width is measured to the –3 dB point, as is usually quoted for sonars. ***(2)*** The Omni mode is identical to the shallow-water mode except that the source output is 220 dB rms. The Omni mode is normally used only during start up. ***(3)*** The RDT mode is normally used during deep-water operation and has a 237 dB rms source output. In the RDT mode, each "ping" consists of five successive transmissions, each ensonifying a beam that extends 2.67 degrees fore-aft and ~30 degrees in the cross-track direction. The five successive transmissions (segments)

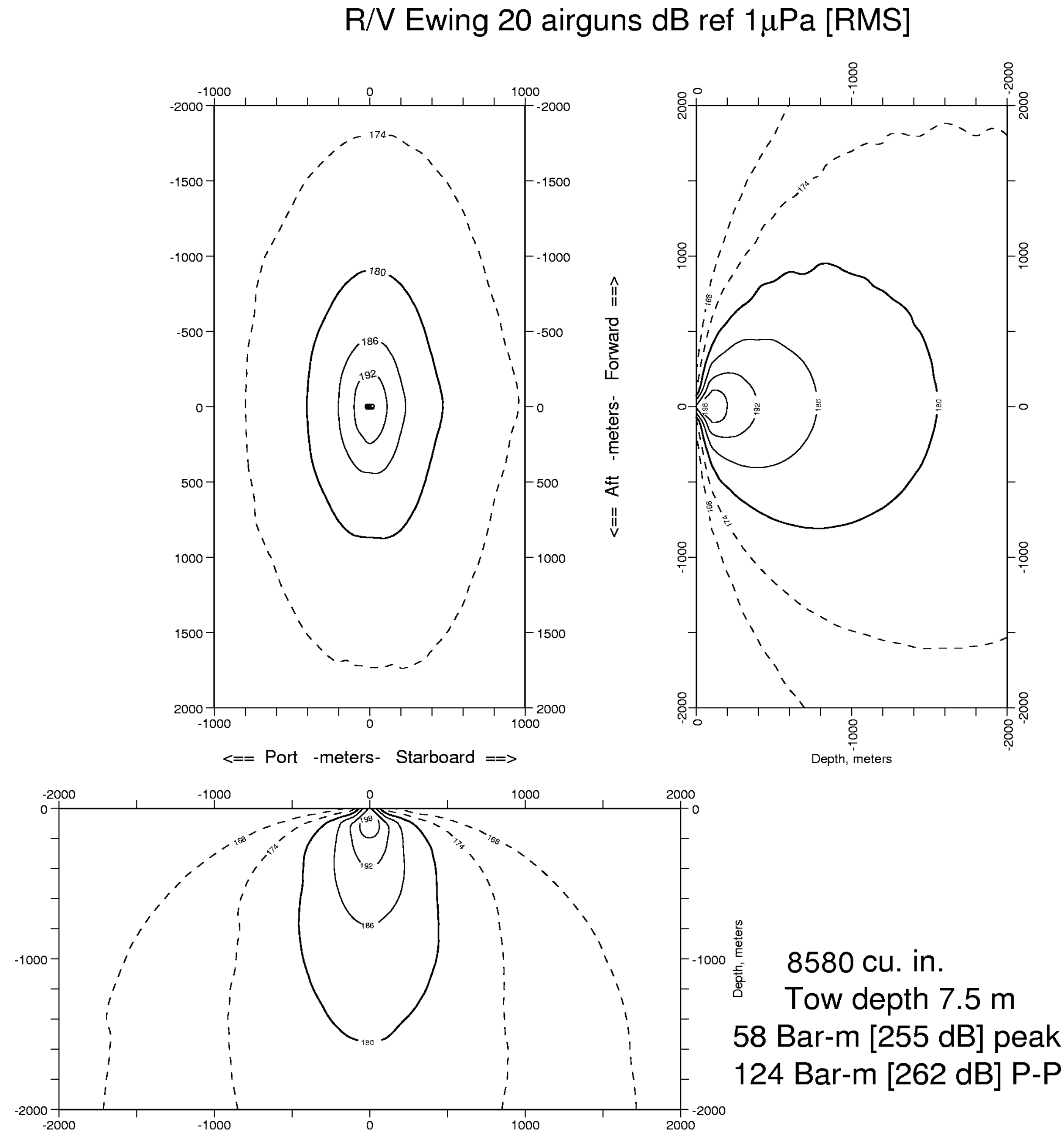


FIGURE 11. Modeled received sound levels from the standard 20-gun array that will be used during L-DEO seismic surveys in 2004.

sweep from port to starboard with minor overlap, spanning an overall cross-track angular extent of about 140 degrees, with tiny (<<1 millisec) gaps between the pulses for successive 30-degree segments. The total duration of the "ping", including all five successive segments, varies with water depth, but is 1 millisec in water depths <500 m and 10 millisec in the deepest water. For each segment, ping duration is 1/5th of these values or 2/5th for a receiver in the overlap area ensonified by two beam segments. The "ping" interval during RDT operations depends on water depth and varies from once per second in <500 m (1640.5 ft) water depth to once per 15 seconds in the deepest water.

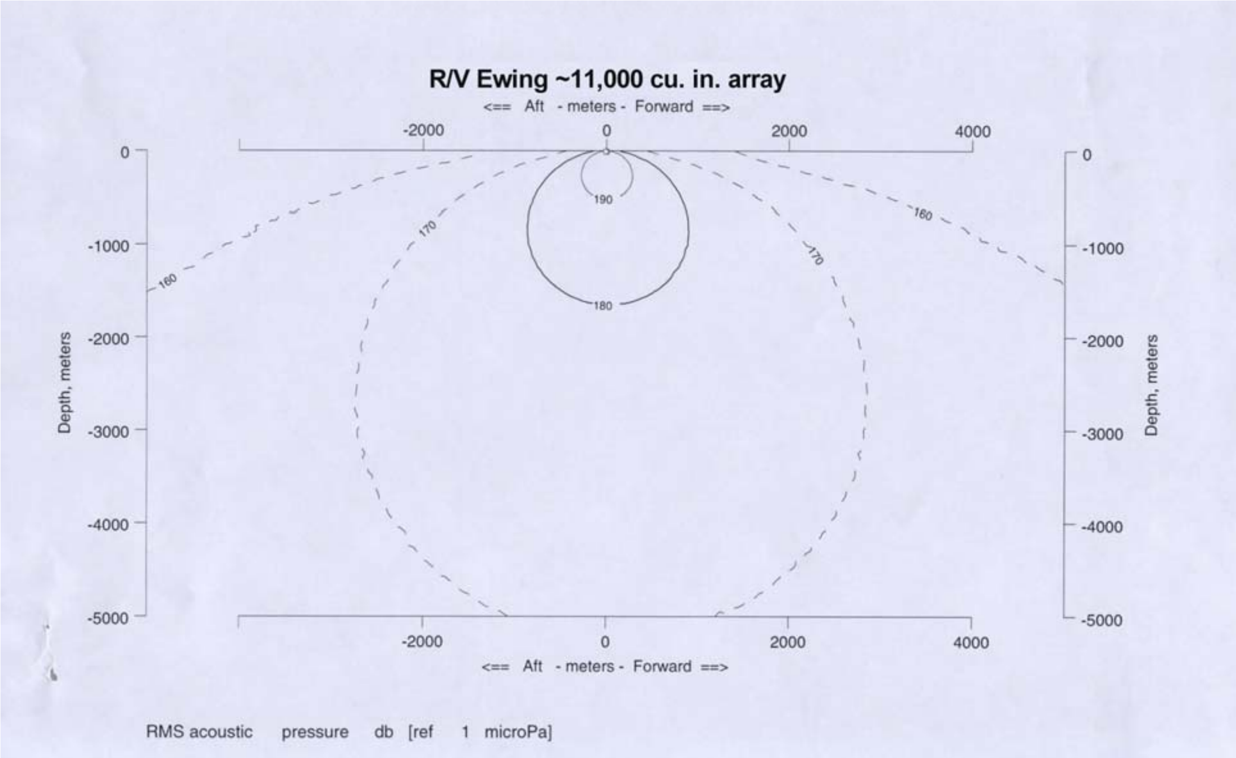


FIGURE 12. Modeled received sound levels from the augmented 20-gun array that will be used during L-DEO sound measurements in the Gulf of Mexico in 2004.

Sub-bottom Profiler

This device is normally operated to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the Hydrosweep. The energy from the sub-bottom profiler is directed downward by a 3.5-kHz transducer mounted in the hull of the *Ewing*. The output varies with water depth from 50 watts in shallow water to 800 watts in deep water. Pulse interval is 1 second but a common mode of operation is to broadcast five pulses at 1-s intervals followed by a 5-s pause.

3.5 kHz Sub-bottom Profiler Specifications

Maximum source output (downward)	204 dB re 1 µPa at 800 watts
Normal source output (downward)	200 dB re 1 µPa at 500 watts
Dominant frequency components	3.5 kHz
Bandwidth	1.0 kHz with pulse duration 4 ms 0.5 kHz with pulse duration 2 ms 0.25 kHz with pulse duration 1ms
Nominal beam width	30 degrees
Pulse duration	1, 2, or 4 ms

TABLE 1. Predicted distances out to which sound levels ≥190, 180, 170 and 160 dB re 1 μPa (rms) might be received from six configurations of airguns used by L-DEO. Based on acoustic modeling by L-DEO. Empirical data from 2003 suggest that these distances tend to be overestimates in deep water but underestimates in shallow water (L-DEO in prep.).

Airgun Array Volume	Airgun Depth in meters (ft)	Predicted (Modeled) RMS Radii in meters (ft)			
		190 dB	180 dB	170 dB	160 dB
210 in^3 (2 GI guns)	6.0 (20	17 (55)	54 (180)	175 (575)	510 (1675)
1350 in^3 (6 airguns)	7.5 (25)	50 (165)	220 (720)	2200 (7220)	2700 (8860)
3005 in^3 (10 airguns)	7.5 (25)	200 (655)	550 (1805)	2000 (6560)	6500 (21,325)
3721 in^3 (12 airguns)	7.5 (25)	200 (655)	600 (1970)	1600 (5250)	7250 (23,790)
8575 in^3 (standard 20 airguns)	7.5 (25)	275 (900)	900 (2955)	2600 (8530)	9000 (29,530)
11,000 in^3 (augmented 20 airguns)	9.0 (30)	300 (985)	925 (3035)	2900 (9515)	9200 (30,185)

Measurements of Airgun Sounds

The 2004 program is designed to document the received levels of the airgun sounds, relative to distance, during operation of each standard configuration of airgun array deployed from the *Ewing*. Measurements will be made at varying distances from the airgun arrays using suitable electronics installed in an L-DEO spar buoy, and possibly also a bottom-moored buoy, if available. The buoys will be deployed and retrieved by the *Ewing*. The primary source of the acoustic verification data will be the L-DEO spar buoy with two hydrophones hung at 18 m and (at the deep and slope sites) 500 m. The L-DEO buoy has been optimized for this purpose and can be deployed where needed. If the bottom-moored buoy is used, it will most likely be used at the slope and/or deep-water sites, time and resources permitting.

Preliminary results from the 2003 project in the Gulf of Mexico have been used to improve and refine the survey design and equipment for 2004. For example, sequencing the airgun arrays from 6 to 20 airguns while shooting a single line did not provide sufficient data points from any one array configuration, especially at the closer distances. Thus, at each site, a separate calibration line will be run for each of the 6 airgun configurations in 2004. In addition, the L-DEO spar buoy has been improved in design as described later.

The study is designed to obtain comparable sequences of measurements at the three sites. The source vessel will travel toward the buoy(s) from a distance of ~10–15 km away, pass the buoy(s), and then continue out to a distance of ~10–15 km beyond the buoy(s). The 15-km distance will be used at the shallow and slope sites (total line length 30 km, respectively), at least for the larger airgun arrays, and the 10-km distance will be used at the deep-water site (total line length 20 km). Longer lines are planned at the shallow and slope sites than at the deep site because, in 2003, received sound levels diminished below 160 dB re 1 μPa (rms) well within 10 km at the deep site, but not at a shallow site (L-DEO in prep.). Given the time constraints of the 2004 calibration study, the extended 30-km lines will not be used where they are considered unnecessary, i.e., in deep water and/or with smaller airgun configurations.

The source vessel will make six passes at each site, one for each of the six airgun arrays. The maximum estimate of the line-kilometers of airgun or sonar operations is ~640 km, and is broken down as follows.

- ~180 km at the shallow site (30 km × six lines)
- ~180 km at the slope site (30 km × six lines)
- ~120 km at the deep-water site (20 km × six lines)
- Up to ~240 km of "contingency and other" shooting will occur during turns between lines, repeat passes, testing, or ramp-ups, etc.

If time permits, a total of ~50 km of port/starboard crossing shots would be done at each site, for a possible additional 150 km of line. This would be in lieu of a portion of the ~240 km of "contingency and other" operations mentioned above. Thus, total line-kilometers would remain ~640 km.

L-DEO Spar Buoy.—The configuration of the L-DEO spar buoy in 2004 will be similar to that used for the Gulf of Mexico calibration study in 2003, but various improvements will be made to the buoy based on experience in 2003 (LGL Ltd. 2003c; L-DEO in prep.).

The L-DEO spar buoy is 0.5 m in diameter and 8 m long; it has GPS position determination, a strobe light, internal flotation, and battery power to operate for three days. The buoy has a 16-bit digitizer with 2^{12} front end gain ranging, variable sampling rate (5, 10, 20, 50 kHz), an eight channel multiplexer, and a two-way radio-telemetry system to receive commands from the *Ewing* and transmit data to the ship. Received sound levels that are telemetered to the *Ewing* will be recorded using state-of-the-art equipment on board the vessel.

The spar buoy will have two hydrophones suspended from the surface to receive the airgun signals at standard depths under the surface. One hydrophone will be suspended at a standard shallow-water depth of 18–25 m, and the second hydrophone will be suspended near 500 m (or a shallower depth when deployed in water <500 m deep). The 18–25 and 500 m hydrophone depths were also used during the 2003 calibration study.

This buoy will operate on an "at demand" basis and data will be recovered in near real time via radio telemetry from the buoy. A radio signal from the ship will select the parameters of the sampling, including the gains, sampling rate, and data channel to be digitized from the multiplexer in the buoy. A block of data (including 3–5 seismic pulses) will be collected at the buoy and transmitted back to the ship. Data transmission from the buoy to the ship will take up to six times longer than data acquisition by the buoy. Thus data from the spar buoy will not be continuous. The number of samples that will be obtained will be chosen to provide sufficient data to confirm the models over the distances of interest.

The hydrophones used in 2004 will have a broader response function than those used in 2003. In addition, the Global Positioning System (GPS) on the spar buoy is expected to function (it did not function effectively in 2003). Depending on what other recording systems are available, L-DEO hopes to be able to extend the length of the hydrophone cable to better characterize signal strength at depth. A depth gauge will be attached to the deep hydrophone in 2004 so that its true depth can be recorded, even when local currents drag the hydrophone cable away from vertical. (No depth gauge was attached to the deep hydrophone during the 2003 calibration study.)

EARS or Similar Bottom-Moored Buoy.—EARS buoys sample sounds continuously for long periods of time and are part of an ONR-funded study. An EARS buoy is suitable for recording high-level sounds such as those from a nearby airgun array. It is possible that one bottom-moored EARS buoy—if available—may be deployed and retrieved at the deep and/or intermediate study sites, time and resources permitting. If so, a single hydrophone would be positioned about 250 m above the bottom. It is currently not known if an EARS (or similar) buoy can be used during this cruise. A bottom-moored buoy would provide continuous sound measurements for each pass of the ship toward and past the buoy. However, the data from an EARS buoy would not be available until it is recovered and the data are downloaded and processed by University of New Orleans scientists (headed by Dr. G.E. Ioup) who operate the buoys.

Data Reduction.—The acoustical measurements via the L-DEO spar buoy will be obtained in near real time by L-DEO acoustical staff who will be aboard the *Ewing*. If EARS data are obtained, they will be transferred at a later date from the University of New Orleans to L-DEO. The data from the spar buoy (and the EARS buoy, if used) will be analyzed by the L-DEO acoustical development group and compared to the sound levels that have been predicted by the L-DEO models used to estimate the safety radii.

Sound measurements will be made and reported using the standard measures that have been used during other recent studies of seismic and marine mammals (Greene et al. 1997; McCauley et al. 1998, 2000a,b). Pulse duration will be defined as the period from the time when 5% of the energy has arrived to the time when 95% of the energy has arrived. The rms (root-mean-square) pressure level will be computed for this pulse duration. In addition to these "rms over the pulse duration" measures, sound level measurements will also include peak-to-peak, zero-to-peak, and energy values. Results will be reported to NMFS and will also be useful in making any necessary refinements in safety radii during future operations by the *Ewing.*

II. DATES, DURATION AND REGION OF ACTIVITY

The date(s) and duration of such activity and the specific geographical region where it will occur.

The *Ewing* is scheduled to conduct the 2004 acoustic measurement study at three locations in the northern Gulf of Mexico (Fig. 1) from ~13 to 20 April 2004. It is anticipated that the 7 days (~168 hr) of the cruise will be divided approximately as follows: ~48 hr (2 days) at the slope site, ~24 hr (1 day) at the shallow site, and ~24 hr (1 day) at the deep-water site (Fig. 1). This assumes that nighttime operation of the airguns will be possible at the deep and shallow sites. The remainder of the non-shooting time (72 hr or 3 days) will be used for transit between sites and for deployment of the L-DEO spar buoy (and possibly a bottom-moored buoy). However, the exact dates and durations at each site are unknown, as overall timing and effort may vary due to weather conditions or the need to repeat some measurements if data quality is substandard. Furthermore, start and end dates of the study may vary depending on the availability of the *Ewing* relative to its prior scheduled cruises. Insofar as practical, the airgun operations will be done in the absence of nearby cetaceans, especially sperm whales and beaked whales. Any exposures of these mammals to airgun sounds will be incidental, not intentional.

As summarized previously, airguns will be fired by day and night (up to 24 hr/d) at the shallow and deep-water sites, but only during daylight hours (~12 hr/d) at the slope site. Beaked whales and some other species tend to concentrate in continental slope areas (see Fig. 1 and § III/IV, below). Limiting airgun operations at the slope site to daylight hours will avoid any potential exposure of beaked whales (and other species) at that site to airgun sounds during the night, when they are unlikely to be detected by visual monitoring.

III. Species and Numbers of Marine Mammals in Area

The species and numbers of marine mammals likely to be found within the activity area.

In the Gulf of Mexico, 28 cetacean species and one species of manatee are known to occur (Jefferson and Schiro 1997; Würsig et al. 2000; Table 2). Seven of these species are listed as endangered under provisions of the U.S. Endangered Species Act (ESA), including the sperm, North Atlantic right, humpback, sei, fin, and blue whales, as well as the West Indian manatees. In addition to the 28 species known to occur in the Gulf of Mexico, another three species of cetaceans could potentially occur there: the long-finned pilot whale *Globicephala melas*, the long-beaked common dolphin *Delphinus capensis*, and the short-beaked common dolphin *Delphinus delphis* (Table 2). Any pinniped sighted in the study area would be extralimital.

To avoid redundancy, we have included the required information about the species and (insofar as it is known) numbers of these species in Section IV, below.

IV. Status, Distribution and Seasonal Distribution of Affected Species or Stocks of Marine Mammals

A description of the status, distribution, and seasonal distribution (when applicable) of the affected species or stocks of marine mammals likely to be affected by such activities

Sections III and IV are integrated here to minimize repetition.

The marine mammals that occur in the proposed survey area (Table 2) belong to three taxonomic groups: the odontocetes or toothed cetaceans, such as dolphins, sperm whales, and beaked whales; the mysticetes or baleen whales; and sirenians, i.e., the West Indian manatee. The odontocetes and mysticetes are the primary subjects of this IHA Application to the NMFS. In the U.S., manatees are managed by the Fish & Wildlife Service.

TABLE 2. The habitat, abundance, and conservation status of marine mammals that are known to occur in the Gulf of Mexico.

Species	**Habitat**	**Occurrence in Gulf of Mexico[1]**	**Abundance in Gulf and in North Atlantic[2]**	**ESA[3]**	**IUCN[4]**	**CITES[5]**
Odontocetes						
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	530 (0.31)[a] *13,190* [b]	Endangered *	Vulnerable	I
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	Common	733[c,d] *536 (0.45)* [e,d]	Not listed	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	Common	N.A.	Not listed	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Rare	159[c] *3196 (0.34)* [e,f]	Not listed	Data Deficient	II
Sowerby's beaked whale (*Mesoplodon bidens*)	Pelagic	Extralimital; not seen in southern Gulf	117 (0.38)[a,g]	Not listed	Data Deficient	II
Gervais' beaked whale (*Mesoplodon europaeus*)	Pelagic	Uncommon	N.A.	Not listed	Data Deficient	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Rare	N.A.	Not listed	Data Deficient	II
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	Common	852 (0.31)[a]	Not listed	Data Deficient	II
Bottlenose dolphin (*Tursiops truncatus*)	Continental Shelf, coastal and offshore	Common	5618 (0.26)[h] 50,247 (0.18)[l] 3499 (0.21)[j] 4191 (0.21)[k] 9912 (0.12)[m] 5141[n] *50,092* [e,o]	Not listed[§]	Data Deficient	II
Pantropical spotted dolphin (*Stenella attenuata*)	Mainly pelagic	Common	46,625[c] *13,117 (0.56)*[e]	Not listed	Lower Risk/ Conservation Dependent	II
Atlantic spotted dolphin (*Stenella frontalis*)	Mainly coastal waters	Common	3213[a] *52,279* [p]	Not listed	Data Deficient	II
Spinner dolphin (*Stenella longirostris*)	Pelagic in Gulf of Mexico	Common	11,251[c]	Not listed	Lower Risk/ Conservation Dependent	II
Clymene dolphin (*Stenella clymene*)	Pelagic	Common	10,093[c]	Not Listed	Data Deficient	II

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and in North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	Common	4858 (0.44)[a] *61,546 (0.40)*[e]	Not listed	Lower Risk/ Conservation Dependent	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	Possible	N.A.	Not listed*	N.A.	II[+]
Long-beaked common dolphin (*Delphinus capensis*)	Coastal	Possible	N.A.	Not Listed	N.A.	II[+]
Fraser's dolphin (*Lagenodelphis hosei*)	Water >1000 m	Common; has not been seen in study area	127 (0.90)[a]	Not listed	Data Deficient	II
Risso's dolphin (*Grampus griseus*)	Waters 400-1000 m	Common	3040[c] *29,110 (0.29)*[e]	Not listed	Data Deficient	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Common	3965 (0.39)[a]	Not listed	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Oceanic	Uncommon	518 (0.81)[a]	Not listed	Data Deficient	II
False killer whale (*Pseudorca crassidens*)	Pelagic	Uncommon	817[c]	Not listed	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	277 (0.42)[a] *6600* [q]	Not listed	Lower Risk/ Conservation Dependent	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	Common	1471[c] *792,524* [r]	Not listed*	Lower Risk/ Conservation Dependent	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Possible	N.A.	Not listed*	N.A.	II
Mysticetes North Atlantic right whale (*Eubalaena glacialis*)	Coastal and shelf waters	Extralimital; not seen in southern Gulf	291[e]	Endangered *	Endangered	I
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	Rare	*11,570* [s] *10,600* [t] *10,000* [u]	Endangered *	Vulnerable	I
Minke whale (*Balaenoptera acutorostrata*)	Coastal waters	Rare	*149,000* [v]	Not listed	Lower Risk/ Near Threatened	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Uncommon; not seen in southern Gulf	35 (1.10)[a]	Not listed	Data Deficient	I

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and in North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Rare	*12–13,000* [w]	Endangered *	Endangered	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Rare	2814[e] *47,300* [v]	Endangered *	Endangered	I
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and oceanic waters	Extralimital	*308*[e,x]	Endangered *	Endangered	I
Sirenian West Indian manatee (*Trichechus manatus*)	Freshwater and coastal waters	Common along the coast of Florida; Rare in other parts of Gulf	86[y] 340[z]	Endangered *	Vulnerable	I
Pinnipeds Hooded seal (*Cystophora cristata*)	Coastal	Vagrant	*300,000^*	Not listed	N.A.	N.A.

N.A. - Data not available or species status was not assessed.
[1] Occurrence from Würsig et al. (2000).
[2] Estimate for North Atlantic population shown in italics. The Coefficient of Variation (CV) is a measure of a number's uncertainty or variability on a proportional basis and is shown in parentheses.
[3] Endangered Species Act (Waring et al. 2001, 2002).
[4] IUCN Red List of Threatened Species (2002).
[5] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2002).
* Listed as a strategic stock under the U.S. Marine Mammal Protection Act.
[§] Only the Gulf of Mexico bay, sound, and estuarine stocks are strategic.
[a] Abundance estimate for the northern Gulf of Mexico stock from Waring et al. (2001, 2002).
[b] *g*(o) corrected total estimate for the Northeast Atlantic, Faroes-Iceland, and the U.S. east coast (Whitehead 2002).
[c] Abundance estimate for the northern Gulf of Mexico stock from Davis et al. (2000).
[d] Estimate for *Kogia* sp.
[e] Abundance estimate for U.S. Western North Atlantic stocks (Waring et al. 2002).
[f] This estimate is for *Mesoplodon* and *Ziphius* spp.
[g] Estimate for all *Mesoplodon* spp. and perhaps including some *Ziphius* spp.
[h] Gulf of Mexico continental shelf edge and continental slope stock.
[i] Gulf of Mexico outer continental stock (Waring et al. 2002).
[j] Western Gulf of Mexico coastal stock (Waring et al. 2002).
[k] Northern Gulf of Mexico coastal stock (Waring et al. 2002).
[m] Eastern Gulf of Mexico coastal stock (Waring et al. 2002).
[n] Gulf of Mexico bay, sound, and estuarine stocks (Waring et al. 2002).
[o] Abundance estimate is a total for the Western North Atlantic offshore and coastal stock.
[p] Abundance estimate for the Western North Atlantic offshore and coastal stocks combined.
[q] Estimate for Icelandic and Faroese waters (Reyes 1991).
[r] This is a combined estimate for *Globicephala sp.* for the Northeast Atlantic (Buckland et al. 1993) and for the

Western North Atlantic stock (Waring et al. 2002).
[s] This estimate is for the Atlantic Basin (Stevick et al. 2001, 2003).
[t] Estimate for the entire North Atlantic (Smith et al. 1999).
[u] Estimate for the Southern Hemisphere (IWC 2003).
[v] Estimate is for the North Atlantic (IWC 2003).
[w] Abundance estimate for the North Atlantic (Cattanach et al. 1993).
[x] Minimum abundance estimate.
[y] Antillean Stock in Puerto Rico only.
[z] Antillean Stock in Belize (Reeves et al. 2002).
[^] Estimate for the northwest Atlantic (Seal Conservation Society 2001).
[+] No distinction is made between *D. delphis* and *D. capensis.*

In the Gulf of Mexico, the southwestern Florida continental shelf and the narrow shelf south of the Mississippi River have been identified as important habitats for cetaceans (Baumgartner et al. 2001; Davis et al. 2002). In the northern Gulf of Mexico, cetaceans are concentrated along the continental slope near cyclonic eddies and confluence areas of cyclonic-anticyclonic eddy pairs. In these areas, nutrient-rich water is thought to increase zooplankton stocks and thus prey abundance (Davis et al. 2002). The narrow continental shelf south of the Mississippi River delta appears to be an important habitat for some cetacean species (Baumgartner et al. 2001; Davis et al. 2002). Low salinity, nutrient-rich waters may occur over the continental slope near the mouth of the Mississippi River or be entrained within the confluence areas and transported beyond the continental slope, creating a deep-water environment with increased productivity (Davis et al. 2002). The rate of primary productivity and the standing stocks of chlorophyll and plankton are higher in this area as compared with other regions in the oceanic Gulf (Dagg et al. 1988; Ortner et al. 1989; Müller-Karger et al. 1991). This increased productivity may explain the presence of a breeding population of endangered sperm whales within 100 km of the Mississippi River delta (Davis et al. 2002). The southwestern Florida continental shelf may be another region of high productivity, and an important habitat for several cetacean species (Baumgartner et al. 2001).

Several species of cetaceans are also widespread outside the above-described areas, on the continental shelf and/or along the shelf break. These include bottlenose dolphins, Atlantic spotted dolphins, and Bryde's whales (Davis et al. 2002). In general, cetaceans in the Gulf of Mexico seem to be partitioned by their habitat preferences, which are likely based on prey distribution (Baumgartner et al. 2001).

No species of pinnipeds are known to occur currently in the Gulf of Mexico. The Caribbean monk seal, *Monachus tropicalis*, has been extinct since the early 1950s; the last verified sighting in the Gulf of Mexico was in 1932 (Würsig et al. 2000). The California sea lion (*Zalophus californianus*), which was introduced to the Gulf of Mexico, has not been reported there since 1972 (Würsig et al. 2000). Vagrant hooded seals could potentially occur in the Gulf of Mexico and the project area. Hooded seals have been seen as far south as the Caribbean (Rice 1998; Mignucci-Giannoni and Odell 2001; Reeves et al. 2002).

During the 2003 acoustical calibration study in the Gulf of Mexico from 28 May to 2 June, a total of seven visual sightings of marine mammals were documented from the *Ewing*; these included a total of ~38–40 individuals (LGL Ltd. 2003c). In addition, three sea turtles were sighted in 2003 from the *Ewing*. These totals include times when airguns were not operating as well as times when airguns were operating. Visual monitoring effort consisted of 60.94 hr of observations (all in daylight) along 891.5 km of vessel trackline on seven days. In addition, passive acoustical monitoring occurred for ~32 hours during the period 28 May–2 June 2003. Most of the monitoring effort (visual as well as acoustic) occurred when airguns were not operating, since airgun operations were limited during the 2003 study. No marine mammals were detected during acoustic monitoring. Marine mammal and sea turtle sightings and locations during the 2003 calibration study are summarized in Appendix A.

Odontocetes

Numerous species of toothed whales occur in the Gulf of Mexico but most of these species occur predominantly in relatively deep offshore water (Table 2). Thus, most of the species discussed below are most likely to be encountered during the present project near the intermediate and deep-water sites rather than the shallow site. Only two species of odontocetes, the bottlenose dolphin and Atlantic spotted dolphin, prefer the shallower waters of the Gulf of Mexico.

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). In the western North Atlantic, they are often seen along the continental shelf (Würsig et al. 2000). The sperm whale is the most abundant large whale in the Gulf of Mexico (Würsig et al. 2000). Adults as well as young sperm whales have been sighted in those waters (Würsig et al. 2000). It is likely that a resident population of sperm whales exists in the Gulf (Schmidly and Shane 1978 *in* Würsig et al. 2000), although year-round residency has not yet been confirmed in the area (Würsig et al. 2000). An ongoing study with satellite-linked tags (Mate et al. in press) is likely to provide relevant information on this topic. The sperm whale is predominantly a deep-water species.

In the northern Gulf, sperm whales are common in the central and eastern regions (Würsig et al. 2000). Concentrations of sperm whales occur south of the Mississippi River Delta, where upwelling is known to occur, in water 1000 m or 3281 ft deep (Biggs et al. in press; Mullin and Hoggard 2000; Würsig et al. 2000; Mullin et al. 1991), and.~300 km or 162 n.mi. east of the Texas-Mexico border (Würsig et al. 2000). Published information about the seasonal distribution and movements of sperm whales in the Gulf of Mexico is limited (Mate in press). However, a recent satellite tagging study showed that a sperm whale initially tagged in the northern Gulf of Mexico in 2001 spent 95 days there, before taking 23 days to traverse the upper Gulf, and proceeding to the Gulf of Campeche, Mexico, where it spent at least 19 days (Mate in press). The seasonal distribution of sperm whales in the Gulf of Mexico could be affected by individual variability or year-to-year variation in the environment, such as an El Niño event, as well as individual variability (Mate in press).

Sperm whales typically occur outside of anticyclonic features (Biggs et al. 2000; Baumgartner et al. 2001; Davis et al. 2002). Anticyclonic features, where downwelling is known to occur, have lower zooplankton biomass (Biggs 1992), and depressed isotherms, which could affect the availability of prey (Baumgartner et al. 2001). Sperm whale prey such as cephalopods may be located deeper in areas with depressed isotherms, and may thus be less accessible or energetically more expensive to feed on as compared to cephalopods outside of anticyclonic features (Baumgartner et al. 2001). Biggs et al. (in press) noted that cyclonic eddies could be important feeding grounds for sperm whales along the continental slope.

Sperm whales generally occur in deep waters, along continental slopes (Rice 1989; Davis et al. 1998; 2002; Ortega-Ortiz 2002). In the Gulf, they are most often seen along the lower continental slope, with water depths >1000 m or 3281 ft (Baumgartner et al. 2001; Davis et al. 2002). Sperm whales routinely dive to depths of hundreds of meters and may occasionally dive to 3000 m (Rice 1989). They are capable of remaining submerged for longer than two hours, but most dives are considerably shorter (Rice 1989). A telemetry study of a sperm whale in the southeast Caribbean conducted by Watkins et al. (2002) showed that most dives were deep dives averaging 990 m or 3248 ft, and ranged from 420 to 1330 m (1378–4364 ft). Deep dives lasted an average of 44.4 min, ranging from 18.2 to 65.3 min (Watkins et al. 2002). Thode et al.

(2002) noted that sperm whale dives in the Gulf of Mexico usually last between 30 and 40 min; he also noted descent rates ranging from 79 to 96 m/min.

Sperm whales occur singly (older males) or in groups of up to 50 individuals. In the Gulf of Mexico, they have been seen singly or in groups (Mullin and Hoggard 2000). Biggs et al. (in press) noted that sperm whales in the north-central Gulf were mostly detected in groups of 2–9 animals. Weller et al. (1996) noted a group of 12 sperm whales in the Gulf, which were interacting with several short-finned pilot whales. Sperm whale distribution is thought to be linked to social structure; females and juveniles generally occur in tropical and subtropical waters, whereas males are wider ranging and occur in higher latitudes (Waring et al. 2001). Sperm whales are seasonal breeders, but the mating season is prolonged. In the Northern Hemisphere, conception may occur from January through August (Rice 1989), although the peak breeding season is from April to June (Best et al. 1984). Thus, calves may be sighted in the proposed survey area in April. Females bear a calf every 3–6 years (Rice 1989), and gestation is 14–16 months.

The sperm whale is the one species of odontocete discussed here that is listed under the ESA and the one species of odontocete that is listed in CITES Appendix I (Table 2). Although this species is formally listed as ***endangered*** under the ESA, it is a relatively common species on a worldwide basis, and is not biologically endangered. However, abundance in the Gulf of Mexico may be only on the order of 500 animals (Davis et al. 2000; Waring et al. 2001, 2002). As noted above, these animals are unlikely to occur near the shallow site, but may enter the waters near the intermediate and deep-water sites.

Pygmy Sperm Whale (*Kogia breviceps*)

Pygmy sperm whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). They are difficult to distinguish from dwarf sperm whales. Although there are few useful estimates of abundance for pygmy sperm whales anywhere in their range, they are thought to be fairly common in some areas.

In the western North Atlantic, pygmy sperm whales are known to occur from Nova Scotia to Cuba, and as far west as Texas in the Gulf of Mexico (Würsig et al. 2000). These whales are considered common in the Gulf and occur there year-round (Würsig et al. 2000). They strand frequently along the coast of the Gulf, especially in autumn and winter; this may be associated with calving (Würsig et al. 2000). In the northern Gulf, pygmy sperm whales are typically sighted in waters 100–2000 m or 328–6562 ft deep and their group sizes averaged 1.5 to 2.0 animals (range 1 to 6; Würsig et al. 2000). Densities of pygmy sperm whales were highest in the spring and summer and lower in the fall and winter (Würsig et al. 2000).

These whales are primarily sighted along the continental shelf edge (Hansen et al. 1994; Davis et al. 1998). Baumgartner et al. (2001) noted that they are sighted more frequently in areas with high zooplankton biomass. Pygmy sperm whales mainly feed on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). Pygmy sperm whales occur in small groups of up to six individuals (Caldwell and Caldwell 1989). A group of 10 pygmy sperm whales was sighted during the 2003 calibration study in the Gulf of Mexico (Appendix A).

The gestation period for pygmy sperm whales is 9–11 months and peak calving occurs from autumn to spring (Würsig et al. 2000).

Dwarf Sperm Whale (*Kogia sima*)

Dwarf sperm whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). They are difficult to distinguish from pygmy sperm whales. Although there are few useful estimates of abundance for dwarf sperm whales anywhere in their range, they are thought to be fairly common in some areas. In the western North Atlantic, they are known to occur from Virginia to the Caribbean and the Gulf of Mexico, where they are thought to be common (Würsig et al. 2000). These whales strand frequently along the coast of the Gulf, but not as frequently as pygmy sperm whales (Würsig et al. 2000). They are thought to occur in the Gulf year-round (Würsig et al. 2000).

These whales are primarily sighted along the continental shelf edge and over deeper waters off the shelf, (Hansen et al. 1994; Davis et al. 1998); thus, they are not expected to occur at the shallow project site but may occur at the intermediate and deep-water sites. Baumgartner et al. (2001) noted that they are sighted more frequently in areas with high zooplankton biomass. Barros et al. (1998) suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. Dwarf sperm whales mainly feed on squid, fish and crustaceans. Dwarf sperm whales may form groups of up to 10 animals (Caldwell and Caldwell 1989). A group of two dwarf sperm whales was sighted in waters ~3200 m deep during L-DEO's 2003 acoustical calibration study in the Gulf of Mexico (Appendix A).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

This cosmopolitan species is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It appears to be absent from areas north of 60ºN and south of 50ºS (Würsig et al. 2000). In the western North Atlantic, these whales occur from Massachusetts to Florida, the West Indies, and the Gulf of Mexico (Würsig et al. 2000). In the Gulf of Mexico, they have been sighted on the lower continental slope, where depths are ~2000 m or 6562 ft (Mullin and Hoggard 2000; Davis and Fargion 1996). Most strandings are from the eastern Gulf, especially from Florida (Würsig et al. 2000). Because of its preference for deep-water, the Cuvier's beaked whale is unlikely to be encountered near the shallow project site but may occur at the intermediate and deep-water sites of the project area.

This species is rarely observed and is mostly known from strandings (Leatherwood et al. 1976; NOAA and USN 2001). There are more recorded strandings for Cuvier's beaked whale than for other beaked whales (Heyning 1989). Its inconspicuous blow, deep-diving behavior, and its tendency to avoid vessels may help explain the rarity of sightings. Adult males of this species usually travel alone, but these whales can be seen in groups of up to 25 individuals. In the northern Gulf, group sizes ranged from 1 to 4 individuals (Mullin and Hoggard 2000). Calves are born year-round (Würsig et al. 2000). This species occurs offshore, and typically dives for 20–40 min in water up to 3300 ft (1000 m) deep. The stomach contents of stranded animals are primarily cephalopods, with occasional crustaceans and fish (Debrot and Barros 1994; MacLeod et al. 2003).

Sowerby's Beaked Whale (*Mesoplodon bidens*)

Sowerby's beaked whale occurs in cold temperate waters (Mead 1989). In the western North Atlantic, strandings have been recorded for Newfoundland, Massachusetts, and the Gulf of Mexico (Mead 1989). However, their occurrence in the Gulf is thought to be extralimital (Mead 1989; Würsig et al. 2000).

Gervais' Beaked Whale (*Mesoplodon europaeus*)

The Gervais' beaked whale is mainly oceanic and occurs in tropical and warmer temperate waters of the Atlantic. The distribution of this species is primarily known from stranding records. Strandings may be associated with calving, which takes place in shallow water (Würsig et al. 2000). Very little is known about the seasonality or other aspects of the reproduction of mesoplodonts.

Gervais' beaked whale is more frequent in the western than in the eastern Atlantic (Mead 1989), and occurs from New York to Florida and the Gulf of Mexico (Würsig et al. 2000). In the Gulf of Mexico, strandings were reported for Florida, Texas, the northeastern Gulf, Cuba, and southern Mexico (Würsig et al. 2000). However, most records for this species are from Florida (Debrot and Barros 1992).

Gervais' beaked whale usually inhabits deep waters (Davis et al. 1998). Food habits of this whale have been poorly studied, although Debrot and Barros (1992) noted that these animals likely feed in deep waters and show a preference for mesopelagic cephalopods and fish. Stomach contents have been known to include fish, squid, and mysids (Debrot 1998; Debrot et al. 1998; MacLeod et al. 2003). The calving period is thought to be in spring and summer (Würsig et al. 2000).

Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is found in tropical and warmer temperate waters (Leatherwood and Reeves 1983). Houston (1990) reports that Blainville’s beaked whale is widely, if thinly, distributed throughout the tropical and subtropical waters of the world. Blainville's beaked whales are rarely sighted, and most knowledge on their distribution is derived from stranding data. In the western North Atlantic, this species is found from Nova Scotia to Florida, the Bahamas, and the Gulf of Mexico (Würsig et al. 2000). Stranding records exist for Louisiana, Texas, Mississippi/Alabama, and Florida (Würsig et al. 2000), as well as for the Yucatán (see Ortega-Ortiz 2002). This species has also been sighted in the northern Gulf (Würsig et al. 2000).

There is no evidence that Blainville's beaked whales undergo seasonal migrations, although movements into higher latitudes are likely related to warm currents, such as the Gulf Stream in the North Atlantic. Blainville's beaked whale is mainly a pelagic species, and like other beaked whales, is mainly found in deep waters (Davis et al. 1998). However, Blainville’s beaked whales may occur more frequently than other beaked whales in moderate-depth waters of 200–1000 m (MacLeod et al. 2003). These beaked whales travel in groups of 2 to 12 individuals, and dives can last up to 45 min. They appear to feed on mesopelagic squid and fish (Mead 1989; see also MacLeod et al. 2003).

Rough-toothed Dolphin (*Steno bredanensis*)

Rough-toothed dolphins are widely distributed around the world, but mainly occur in tropical and warm temperate waters (Miyazaki and Perrin 1994). In the western Atlantic, this species occurs between the southeastern United States and southern Brazil (Jefferson 2002). It has been sighted in the northern Gulf, especially in the eastern areas (Würsig et al. 2002). Strandings are known for Texas and Florida (Würsig et al. 2000). It is thought to occur year-round in the Gulf (Würsig et al. 2000).

Rough-toothed dolphins are generally found in moderate sized groups of 10–20 animals, but groups of up to 300 individuals have been seen in some areas (Jefferson 2002). In the Gulf, group sizes range from 2 to 48 individuals (Würsig et al. 2000). They are deep divers and can dive for up to 15 min (Reeves et al. 2002). This species usually inhabits deep waters (Davis et al. 1998), where they prey on fish and cephalopods (Reeves et al. 2002). However, at least in late summer/early autumn, they also occur in continental shelf waters in the northern Gulf (Fulling et al. 2003).

Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed worldwide, mostly in coastal waters, and is expected to be the most common species of dolphin near the shallow-water project site. One group was seen during the 2003 L-DEO project at the shallow site (Appendix A).

In the western North Atlantic, these dolphins occur from Nova Scotia to Florida, the Gulf of Mexico and the Caribbean and southward to Brazil (Würsig et al. 2000). There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters, and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). Both types of bottlenose dolphins have been shown to inhabit waters in the western North Atlantic Ocean, including the Gulf of Mexico (Walker et al. 1999). In the Gulf, the inshore type inhabits shallow lagoons, bays and inlets, and the oceanic population occurs in deeper, offshore waters over the continental shelf (Würsig et al. 2000). The bottlenose dolphin is the most widespread and common cetacean in coastal waters of the Gulf of Mexico (Würsig et al. 2000).

Bottlenose dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m or 656 ft (Davis et al. 1998; 2002), but are also known to occur seaward of the shelf break at depths of 200–750 m or 656–2461 ft (Baumgartner et al. 2001). However, they can dive to depths of 1755 ft (535 m) for periods of up to 12 min (Schreer and Kovacs 1997). Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Groups up to several hundred occur, but smaller pods of 2–15 are more common (Würsig et al. 2000; Fulling et al. 2003). In the northern Gulf, group sizes are typically 1–90 (Mullin and Hoggard 2000). Group size is thought to be affected by habitat structure, and group size tends to increase with water depth (Würsig et al. 2000). Bräger (1993) found that bottlenose dolphins in the northern Gulf of Mexico show seasonal and diel patterns in their behavior. In the summer, they feed mainly during the morning and for a short time during the afternoon, and socializing increases as feeding decreases, with peak socializing in the afternoon (Bräger 1993). During the fall, they spend less time socializing and traveling, and feed throughout the day (Bräger 1993). During the summer, this species feeds mainly on fish, but during the winter, bottlenose dolphins in the northern Gulf of Mexico feed primarily on cephalopods and crustaceans (Bräger 1993).

Pantropical Spotted Dolphin (*Stenella attenuata*)

As its name indicates, the pantropical spotted dolphin can be found throughout tropical oceans of the world (Waring et al. 2001). In the western North Atlantic, it occurs from North Carolina to the West Indies and down to the equator (Würsig et al. 2000). It is the most common species of cetacean in the deeper Gulf of Mexico (Würsig et al. 2000; Davis and Fargion 1996). During 1989–1997, this species was mainly seen in the north-central Gulf from south of the Mississippi Delta to west of Florida (Würsig et al. 2000). One sighting of pantropical spotted dolphins was made during L-DEO's 2003 Gulf of Mexico acoustical calibration study (Appendix A).

Pantropical spotted dolphins usually occur in waters >1000 m or 3281 ft deep, and in most areas rarely occur over the continental shelf or shelf edge (Davis et al. 1998; Baumgartner et al. 2001; Waring et al. 2001). Baird et al. (2001) found that this species dives deeper at night than during the day, and that swimming speed also increased after dark. These results, together with the series of deep dives recorded immediately after sunset, suggest that pantropical spotted dolphins feed primarily at night on organisms associated with the deep-scattering layer as it rises toward the surface after dark (Baird et al. 2001).

Pantropical spotted dolphins are extremely gregarious and form schools of hundreds or even thousands of individuals. These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994).

Atlantic Spotted Dolphin (*Stenella frontalis*)

Atlantic spotted dolphins are distributed in tropical and warm temperate waters of the western North Atlantic (Leatherwood et al. 1976). Their distribution extends from southern New England, south through the Gulf of Mexico and the Caribbean, to Venezuela (Leatherwood et al. 1976; Perrin et al. 1994a). Atlantic spotted dolphins are common in the Gulf of Mexico (Würsig et al. 2000), with higher densities in the northeast than in the northwest Gulf (Fulling et al. 2003).

Atlantic spotted dolphins usually inhabit shallow waters on the continental shelf inshore of the 250-m isobath (Davis et al. 1998; 2002; Fulling et al. 2003). In the eastern Gulf of Mexico, this is the predominant species in waters 20–180 m deep (Griffin and Griffin 2003). They move inshore in the spring and summer, perhaps associated with the arrival of carangid fishes (Würsig et al. 2000). They mainly feed on fish, such as herring, anchovies, and flounder (Würsig et al. 2000). Davis et al. (1996) found that most dives of Atlantic spotted dolphins were shallow and of short duration, regardless of the time of day. Spotted dolphins usually dove to depths of 4 to <30 m, but the deepest dives recorded were 40–60 m or 131–197 ft (Davis et al. 1996). Most of the dives were less than 2 min in duration (Davis et al. 1996). This species can be seen in pods of up to 50 or more animals, but smaller groups of 6–10 animals are more common (Würsig et al. 2000). In the Gulf, group sizes range from 1 to 85 individuals (Mullin and Hoggard 2000).

Atlantic spotted dolphins reach sexual maturity at 8–15 years of age, and females' first parturition usually occurs when they are 12 years old, with an average calving interval of 2.96 years (Herzing 1997). They mate and calve in summer (Würsig et al. 2000). This species produces underwater sounds that range from 0.1 Hz to 8 kHz. They are also able to produce ultrasounds when using echolocation (Thomson and Richardson 1995). Like other toothed whales, they probably have good hearing sensitivity at moderate and high frequencies (8–90 kHz), with diminishing sensitivity at progressively lower frequencies, and relatively poor sensitivity to low frequency sounds.

Spinner Dolphin (*Stenella longirostris*)

Spinner dolphins are distributed in oceanic and coastal tropical waters. Although the spinner dolphin is generally an offshore, deep-water species, its distribution in the Atlantic is mostly unknown (Waring et al. 2001). In the western North Atlantic, it occurs from South Carolina to Florida, the Caribbean, Gulf of Mexico, and southward to Venezuela (Würsig et al. 2000). Almost all sightings in the Gulf of Mexico have been made east and southeast of the Mississippi Delta, in areas deeper than 100 m or 328 ft (Würsig et al. 2000).

Spinner dolphins typically inhabit deep waters (Davis et al. 1998). They usually feed at night on mesopelagic fish, squid, and shrimp that are in waters 200–300 m or 656–984 ft deep (Perrin and Gilpatrick 1994). This species is extremely gregarious and usually forms large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Spinner dolphins can be seen in groups of 30 to hundreds of individuals, or even thousands (Würsig et al. 2000). In the Gulf, they have been sighted in groups of 9 to 750 individuals (Würsig et al. 2000). Spinner dolphins can give birth at any time of year. Their approximate gestation period is 9.5–10.7 months (Berta and Sumich 1999). These dolphins utilize sounds that range from 1–22.5 kHz and ultrasounds up to 65 kHz (review by Thomson and Richardson 1995).

Clymene Dolphin (*Stenella clymene*)

Clymene dolphins usually occur in tropical and warm waters of the Atlantic Ocean. These animals are found off the eastern United States (including the Gulf of Mexico), south to Brazil, and across the Atlantic to West Africa (Mullin et al. 1994a; Fertl et al. 2003). In the Gulf of Mexico, they are widely distributed in the western oceanic Gulf during spring and the northeastern Gulf during summer and winter (Würsig et al. 2000).

Clymene dolphins typically inhabit areas where sea surface temperatures range from 22.8 to 29.1°C and water depths from 704 to 3064 m or 2310 to 10,053 ft (Mullin et al. 1994a; Davis et al. 1998). However, there are a few records in shallower waters (Fertl et al. 2003). They usually feed on small mesopelagic fish and squid (Perrin and Mead 1994). Composition of pods, based on mass strandings, has shown evidence of sexual segregation. i.e., groups tend to consist largely of one sex or the other (Jefferson et al. 1995). The estimated pod size for these dolphins is usually 2 to 100 animals, although larger pods occasionally occur (Mullin et al. 1994a; Würsig et al. 2000; Fertl et al. 2003).

Striped Dolphin (*Stenella coeruleoalba*)

Striped dolphins have a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994b). In the western North Atlantic, this species occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000). A concentration of striped dolphins is thought to exist in the eastern part of the northern Gulf, near the DeSoto Canyon just east of the Mississippi Delta (Würsig et al. 2000).

Striped dolphins are pelagic and seem to prefer the deep water near and beyond the outer edge of the continental shelf (Davis et al. 1998). However, they do occur in coastal waters (Isaksen and Syvertsen 2002). They prey on small fish and small cephalopods (Perrin et al. 1994b). Striped dolphins are gregarious (groups of 20 or more are common) and active at the surface (Whitehead et al. 1998). School composition varies and consists of adults, juveniles, or both adults and juveniles (Perrin et al. 1994b). Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999).

Short-beaked Common Dolphin (*Delphinus delphis*) and
Long-beaked Common Dolphin (*Delphinus capensis*)

Common dolphins are found in tropical and temperate oceans around the world (Evans 1994). The two species of common dolphins have only recently been distinguished. The short-beaked common dolphin is known to occur from Iceland and Newfoundland southward along the coast of the United Sates (Würsig et al. 2000). The long-beaked common dolphin occurs in coastal waters from Venezuela to Argentina (Perrin 2002). The two species are sometime difficult to distinguish at sea. There have not been any confirmed sightings of either species in the Gulf of Mexico, although they may occur in the southern Gulf (Würsig et al. 2000).

Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical species that only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994c). Fraser's dolphins have been sighted in the northwestern Gulf, and have been found stranded in Florida and Texas (Würsig et al. 2000).

Fraser's dolphins typically occur in water at least 1000 m or 3281 m deep. They feed on mesopelagic fish, shrimp, and squid, diving to depths of at least 250–500 m or 820–1641 ft (Dolar 2002). They travel in groups ranging from just a few animals to hundreds or even thousands of individuals (Perrin et al. 1994c), often mixed with other species (Culik 2002). The gestation period is about 12 months, and there may be calving peaks in spring and fall, although calves can be born year-round.

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. In the Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). It has been sighted off Florida and in the western Gulf off the coast of Texas (Würsig et al. 2000). It is likely a year-round resident in the Gulf (Würsig et al. 2000). In the past, Risso's dolphins were sighted in deep continental slope waters of the Gulf in waters 200–1530 m or 656–5020 ft deep (Würsig et al. 2000). However, in recent years, most sightings in the northern Gulf occurred in waters of 200 m or 656 ft depth south of the Mississippi Delta (Würsig et al. 2000). Stranding records exist for Texas and Florida (Würsig et al. 2000).

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging in numbers from two to <250, although groups as large as 4000 have been sighted. The majority of groups consist of fewer than 50 individuals (Kruse et al. 1999). In the Gulf, group sizes range from 1 to 78 individuals (Würsig et al. 2000). Risso's dolphins usually occur over steeper sections of the upper continental slope, in waters 350–975 m or 1148–3199 ft deep (Baumgartner 1997; Davis et al. 1998). They usually feed on squid and other deepwater prey (Kruse et al. 1999). In the North Atlantic, the calving period is thought to be summer (Würsig et al. 2000).

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical and pelagic species (Perryman et al. 1994), in the western Atlantic ranging from the Gulf of Mexico to southern Brazil (Rice 1998). These whales occur mainly between 20ºN and 20ºS; occasional occurrences in temperate regions are likely associated with warm currents (Perryman et al. 1994; Reeves et al. 2002). In the Gulf, they have been sighted in the northwest in waters 200–2000 m or 656–6562 ft deep, from Texas to Mississippi (Würsig et al. 2000). Strandings have also been reported for Texas and Louisiana (Würsig et al. 2000).

Melon-headed whales are oceanic and occur in offshore areas (Perryman et al. 1994), as well as around oceanic islands. Mullin et al. (1994b) noted that they are usually sighted in water >500 m or 1640 ft deep, and away from the continental shelf. Melon-headed whales tend to travel in large groups of 100 to 500 individuals, but have also been seen in herds of 1500 to 2000 individuals. Melon-headed whales may also form mixed species pods with Fraser's dolphins, spinner dolphins, and spotted dolphins (Jefferson et al. 1993; Carwardine 1995). They appear to feed on squid, fish, and shrimp (Jefferson and Barros 1997; Perryman 2002), although squid appear to be the preferred prey of melon-headed whales (Perryman 2002).

Pygmy Killer Whale (*Feresa attenuata*)

Pygmy killer whales are pantropical (Ross and Leatherwood 1994; Rice 1998). They inhabit deep, warm waters from the Gulf of Mexico to Uruguay in the western Atlantic (Rice 1998). In the western North Atlantic, they occur from the Carolinas to Texas and the West Indies (Würsig et al. 2000). They are thought to occur in the Gulf of Mexico year-round (Würsig et al. 2000). They have been sighted in the Gulf off Texas and in the west-central portion of the northern Gulf, in water 500–1000 m or 1640–3281 ft deep (Würsig et al. 2000). Strandings have also occurred from Florida to Texas, with most strandings occurring in the winter (Würsig et al. 2000). There was one sighting during L-DEO's 2003 project; this involved a group of 10 pygmy killer whales at the deep-water site (Appendix A).

Pygmy killer whales tend to travel in groups of 15–50 individuals, although herds of a few hundred have been sighted (Ross and Leatherwood 1994). The remains of fishes and squid have been found in the stomachs of stranded pygmy killer whales, and they are suspected to attack and sometimes eat other dolphins (Donahue and Perryman 2002).

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer, temperate oceans, especially in deep offshore waters (Odell and McClune 1999). In the western North Atlantic, they occur from Maryland to the Gulf of Mexico and the Caribbean (Würsig et al. 2000). These animals have been sighted in the northern Gulf in waters 200–2000 m or 656–6562 ft deep (Würsig et al. 2000), especially in the eastern regions (Mullin and Hoggard 2000). They are also known to strand in the Gulf; records exist for Cuba, Florida, Louisiana, Texas, and southern Mexico (Würsig et al. 2000).

False killer whales are primarily seen in deep, offshore waters, although sightings have been reported for shallow (<200 m or <656 ft) waters. They are gregarious and form strong social bonds (Stacey and Baird 1991). They travel in pods of 20–100 individuals (Baird 2002), although groups of several hundred are sometimes observed. Recently stranded groups ranged from 28 to over 1000 animals. In the northern Gulf, group sizes ranged from 12–63 animals (Mullin and Hoggard 2000). False killer whales feed primarily on fish and cephalopods, but have been known to attack small cetaceans, California sea lions (S.F. MacLean, LGL Ltd., pers. comm.), and even a humpback whale (Jefferson et al. 1993).

Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan and fairly abundant, globally. Killer whales can be seen from equatorial regions to the polar pack-ice, and they may even ascend rivers. Killer whales are most common in high latitudes, especially in cooler areas where productivity is high. In the western North Atlantic, killer whales occur from the polar ice pack to Florida and the Gulf of Mexico (Würsig et al. 2000). In the Gulf, most sightings have been in waters 200–2000 m or 656–6562 ft deep southwest of the Mississippi Delta (Würsig et al. 2000). There have also been summer reports of these whales off Texas near the 200 m or 656 ft isobath (Würsig et al. 2000).

Killer whales are segregated socially, genetically, and ecologically into three distinct groups: residents, transients, and offshore animals. Resident groups feed exclusively on fish, while transients feed exclusively on marine mammals. Offshore killer whales are less known, and their feeding habits are not strictly defined. Killer whale movements generally appear to follow the distribution of prey.

Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Sightings range from the surf zone to the open sea, though usually within 800 km or 432 n.mi. of shore. Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

Short-finned pilot whales probably have a circumglobal distribution in tropical and warm temperate waters, generally south of 50ºN and north of 40º south (Jefferson et al. 1993; Rice 1998). They occur in deep water at the edge of the continental shelf and over deep submarine canyons (Carwardine 1995). There is some overlap of range with *G. melas*, although *G. macrohynchus* appears to have a more southerly distribution. Water temperature appears to be the primary factor determining the relative distribution of these two species (Fullard et al. 2000).

In the western North Atlantic, this species occurs from Virginia to northern South America, including the Caribbean and Gulf of Mexico (Würsig et al. 2000). They are likely to occur in the Gulf year-round (Würsig et al. 2000). In the northern Gulf, they are most commonly seen in the central and western areas in waters 200–1000 m or 656–3281 ft deep, i.e., along the continental slope (Würsig et al. 2000). They are also known to strand frequently in the Gulf (Würsig et al. 2000).

Short-finned pilot whales appear to form relatively stable, matrilineal groups of up to several hundred individuals (Jefferson et al. 1993) that are generally nomadic. There do not appear to be fixed migrations, but general north-south or inshore-offshore movements occur in relation to prey distribution or incursions of warm water. Gestation lasts about 1 year and calving may occur in winter, spring, or fall (Würsig et al. 2000). Short-finned pilot whales are primarily adapted to feeding on squid (Hacker 1992), although they also take some fishes.

Long-finned Pilot Whale (*Globicephala melas*)

Long-finned pilot whales occur in the temperate North Atlantic (Bernard and Reilly 1999). Although there are no records of long-finned pilot whales in the Gulf, they occur as far south as Georgia, on the eastern coast of the United States (Würsig et al. 2000). Thus, it is possible that extralimital strays may occur in the Gulf (Würsig et al. 2000).

Mysticetes

North Atlantic Right whale (*Eubalaena glacialis*)

North Atlantic right whales occur in the North Atlantic from ~30º to 75ºN (Cummings 1985b). In the western North Atlantic, right whales are found from Iceland to Florida; their occurrence in the Gulf of Mexico is extralimital (Würsig et al. 2000). There have only been two accounts of right whales in the Gulf of Mexico—one sighting of two whales off Florida, and a stranding of a calf or young-of-the-year off the coast of Texas (Würsig et al. 2000). Right whales spend the spring and summer at high latitudes where they feed, and migrate south for mating and calving in the winter (Cummings 1985b).

The number of North Atlantic right whales in the western North Atlantic is estimated at only 291 animals (Waring et al. 2002). The right whale is listed as ***endangered*** under the ESA and by IUCN, and it is listed in CITES Appendix I (Table 2).

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale has a cosmopolitan distribution. Although it is considered to be a mainly coastal species, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). In the western North Atlantic, it occurs from Greenland to Venezuela (Würsig et al. 2000). The majority of humpbacks from the North Atlantic population overwinter in the West Indies (Smith et al. 1999). The western North Atlantic has been estimated to contain 5930–12,580 individuals, with a best estimate of 10,752 for 1992–93 (Stevick et al. 2003).

Although humpbacks only occur rarely in the Gulf of Mexico, several sightings have been made off the west coast of Florida, near Alabama, and off Texas (Würsig et al. 2000); these may have been individuals from the West Indian winter grounds that strayed into the Gulf during migration (Weller et al. 1996; Jefferson and Schiro 1997). A group of six humpbacks was seen about 250 km east of the Mississippi Delta where water depth was 1000 m or 3281 ft in 1997 (Würsig et al. 2000). In addition, humpback songs have been recorded with hydrophones in the northwestern part of the Gulf of Mexico, and two strandings have also been noted for the Gulf (Würsig et al. 2000). Although now relatively common, the humpback whale is listed as ***endangered*** under the ESA and in Appendix I of CITES (Table 2).

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). Although widespread and common overall, they are rather rare in the Gulf of Mexico; however, stranded animals have been found in the Gulf on several occasions (Würsig et al. 2002). These strandings occurred in the winter and spring and may have been northbound whales from the open ocean or Caribbean Sea (Würsig et al. 2002). The minke whale is not listed under the U.S. ESA.

Minke whales migrate northward during spring and summer and can be seen in pelagic water at this time; however, they also occur in coastal areas (Stewart and Leatherwood 1985). Minke whales seem able to find and exploit small and transient concentrations of prey (including both fish and invertebrates) as well as the more stable concentrations that attract multi-species assemblages of large predators. Minke whales are relatively solitary, but usually occur in aggregations of up to 100 animals when food resources are concentrated.

Bryde's Whale (*Balaenoptera edeni*)

Bryde's whale is found in tropical and subtropical waters throughout the world, but rarely in latitudes above 35º. It is the most common mysticete in the tropics (Debrot 1998). The Bryde's whale is the most common baleen whale in the Gulf of Mexico (Würsig et al. 2000). This species seems to occur in the Gulf year-round (Würsig et al. 2000). Bryde's whale does not undertake long migrations, although it may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 *in* Cummings 1985a). However, Debrot (1998) noted that this species is sedentary in the tropics. Bryde's whales are pelagic as well as coastal. In the northern Gulf, Bryde's whales are often sighted in relatively shallow water about 100 m or 328 ft deep (Davis et al. 1998, 2002). In the Gulf of Mexico, this species occurs singly or in groups of up to seven individuals (Mullin and Hoggard 2000).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The sei whale is listed as ***endangered*** under the ESA. The global population is thought to be low, with perhaps 12–13,000 in the North Atlantic (Table 2) and about 2600 of those in the western North Atlantic (Würsig et al. 2000). In the latter area, sei whales occur from the Caribbean and Gulf of Mexico to Newfoundland (Würsig et al. 2000). Sei whales are only seen rarely in the Gulf of Mexico (Würsig et al. 2000).

Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985b), but typically occur in temperate and polar regions. Their population size in the western North Atlantic is estimated at 3600–6300 animals (Würsig et al. 2000). The fin whale is listed as ***endangered*** under the ESA. Fin whales appear to have complex seasonal movements, and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, but migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). Their wintering range extends from the ice edge to the Caribbean. Fin whales are only rarely seen in the Gulf of Mexico. There have been reports of five strandings and up to seven sightings in the Gulf (Würsig et al. 2000).

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, and occurs in coastal, shelf and oceanic waters. Its distribution, at least during times of the year when feeding is a major activity, is specific to areas that provide large seasonal concentrations of euphausiids, which are the blue whale's main prey (Yochem and Leatherwood 1985). The population size in the North Atlantic is estimated at a few hundred (Würsig et al. 2000; Waring et al. 2002). Even though these whales are globally distributed, blue whales are unlikely to be seen in the Gulf of Mexico. Only two reports of blue whales exist for the Gulf of Mexico (Würsig et al. 2000). One stranded animal was found on the Texas coast, and another stranded animal was seen in Louisiana (Würsig et al. 2000). This extralimital species is considered ***endangered*** under the ESA and by IUCN, and it is a CITES Appendix I species (Table 2).

Sirenian

West Indian Manatee (*Trichechus manatus*)

The West Indian manatee occurs in rivers, estuaries, lagoons, and coastal waters from the southeastern United States to Brazil. West Indian manatees have a patchy coastal distribution that is dependent on suitable habitat, including vegetation and fresh water; their numbers are locally reduced due to habitat change, hunting, fisheries, and collisions with boats (Lefebvre et al. 1989).

Manatees swim slowly just below or at the surface of the water, and thus they are vulnerable to boat collisions. They feed on a variety of sea grasses and other vegetation. The West Indian manatee is capable of hearing sounds from 15 Hz to 46 kHz, with the best sensitivity at 6 to 20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

The West Indian manatee is subdivided into two subspecies, the Florida manatee (*Trichechus manatus latirostris*) and the Antillean manatee (*T. m. manatus*). The Florida manatee occurs in the northern Gulf of Mexico and the Antillean manatee is found in the southern Gulf. Except for the Florida coast, manatees are considered rare in the Gulf of Mexico (Würsig et al. 2000). Manatees are typically sighted off the coast of Florida, but have also been observed off of Texas, Louisiana, or Mississippi virtually every summer since 1970 (Würsig et al. 2000). The Florida stock of the West Indian manatee is listed under the ESA as ***endangered***.

The manatee is the one species of marine mammal occurring in the general area of concern that, in the U.S.., is managed by the Fish & Wildlife Service rather than NMFS. However, manatees occur mainly in shallow nearshore (or fresh) water, and are unlikely to occur in or near areas where a seismic vessel could operate. The planned project sites (Fig. 1) are farther offshore than manatees are expected to occur.

Pinnipeds

Hooded Seal (*Cystophora cristata*)

Hooded seals typically inhabit the pack ice zone of the North Atlantic from Baffin Bay, Denmark Strait, northern Greenland Sea, and the Barents Sea, south to the Gulf of St. Lawrence and Newfoundland, southern Greenland, Iceland, and Jan Mayen (Rice 1998). However, hooded seals often wander great distances from their pack-ice habitat. They have been reported as far away as southern California in the Pacific; Florida, Puerto Rico, and the Virgin Islands in the western Atlantic; and the Iberian Peninsula in the eastern Atlantic (Lavigne and Kovacs 1988; Rice 1998; Mignucci-Giannoni and Odell 2001). Thus, vagrant hooded seals could occur in the proposed project area, but if so, they would be extralimital.

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

The type of incidental taking authorization that is being requested (i.e., takes by harassment only, takes by harassment, injury and/or death), and the method of incidental taking.

L-DEO requests an IHA pursuant to Section 101 (a) (5) (D) of the MMPA for incidental take by harassment during its planned acoustical calibration study in the north-central Gulf of Mexico during mid-April 2004. The data obtained during this study will further verify and refine the safety radii that will be used during future L-DEO seismic studies and, more generally, will characterize relationships between received levels and distance for each of the standard configurations of airgun array used by L-DEO.

The operations outlined in Sections I and II have the potential to take marine mammals by harassment. These mammals would probably be exclusively cetaceans, and primarily odontocetes, as described above in § III / IV. Sounds will be generated by the airgun arrays used during the calibration study, by bathymetric sonars, by a sub-bottom profiler sonar, and by general vessel operations. "Takes" by harassment will potentially result when marine mammals near the activities are exposed to the pulsed sounds generated by the airgun array or sonars. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely amongst some of the marine mammals in the general vicinity of the tracklines of the source vessel. No take by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, "MITIGATION MEASURES"). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

By age, sex, and reproductive condition (if possible), the number of marine mammals (by species) that may be taken by each type of taking identified in [section V], and the number of times such takings by each type of taking are likely to occur.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

The anticipated impact of the activity upon the species or stock of marine mammal.

The material for Sections VI and VII has been combined and presented in reverse order to minimize duplication between sections.

- First we summarize the potential impacts on marine mammals of airgun operations, as called for in Section VII. A more comprehensive review of the relevant background information appears in Appendix B. That Appendix is little changed from corresponding parts of § VII in related IHA Applications previously submitted to NMFS concerning L-DEO projects in the following areas:

northern Gulf of Mexico (2003), Hess Deep in the eastern tropical Pacific, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, and southern Gulf of Mexico (Yucatan Peninsula).

- Then we discuss the potential impacts of operations by L-DEO's bathymetric sonars and a sub-bottom profiler.
- Finally, we estimate the numbers of marine mammals that might be affected by the proposed activity in the northern Gulf of Mexico in 2004. This section includes a description of the rationale for L-DEO's estimates of the potential numbers of harassment "takes" during the planned acoustic calibration study, as called for in Section VI.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and perhaps temporary or permanent hearing impairment (Richardson et al. 1995).

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix B (c). Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix B (e). This is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds and small odontocetes seem to be more tolerant of exposure to airgun pulses than are baleen whales.

Masking

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds. Masking effects are discussed further in Appendix B (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Disturbance is one of the main concerns in this project. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

Based on NMFS (2001, p. 9293), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales.

Baleen Whales.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, as reviewed in Appendix B (e), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the case of the migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km (2.4–7.8 n.mi.) from the source. A substantial proportion of the baleen whales within these distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix B (e) have shown that some species of baleen whales, notably bowheads and humpbacks, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa rms.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration and much ship traffic in that area for decades (Appendix A *in* Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987). It is not known whether whales that tolerate exposure to seismic pulses are stressed.

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, systematic work on sperm whales is underway.

Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels. Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when the airguns are firing. However, in a number of monitoring studies there have been indications that small toothed whales tend to head away, or to maintain a somewhat greater distance from the vessel, when the airguns are operating than when they are silent (e.g., Goold 1996a; Calambokidis and Osmek 1998; Stone 2003). Similarly, captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 μPa) before exhibiting aversive behaviors.

There are no specific data on the behavioral reactions of beaked whales to seismic surveys. However, most beaked whales tend to avoid approaching vessels of other types (e.g., Kasuya 1986; Würsig et al. 1998). There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operations, are ongoing nearby—see Appendix B (g). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There has been a recent (Sept. 2002) stranding of Cuvier's beaked whales in the Gulf of California (Mexico) when the L-DEO vesssel *Maurice Ewing* was conducting a seismic survey in the general area. This might be a first indication that seismic surveys can have effects similar to those attributed to naval sonars. However, the evidence with respect to seismic surveys and beaked whale strandings is inconclusive.

All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds, and it is to be expected that they would tend to avoid an operating seismic survey vessel. There were some limited early observations suggesting that sperm whales in the Southern Ocean and Gulf of Mexico might be fairly sensitive to airgun sounds from distant seismic surveys. However, more extensive data from recent studies in the North Atlantic suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (McCall Howard 1999; Madsen et al. 2002; Stone 2003). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico has been done recently (Tyack et al. in press).

Pinnipeds.—Pinnipeds are very unlikely to be encountered during the present project in the northern Gulf of Mexico. If an extralimital pinniped is encountered, it is not likely to show a strong avoidance reaction. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix B (e). These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Manatees.—It is unlikely that any manatees will be encountered in the project area, given their preference for water shallower and closer to shore than that where the seismic vessel is to operate. Little information is available on the responses of manatees to industrial noise sources and no information is available on their reactions to airgun noise. Manatees often attempt to avoid oncoming boats by diving, turning, or swimming away, but their reaction is usually slow and does not begin until the boat is nearby.

Additional details on the behavioral reactions (or the lack thereof) by all types of marine mammals to seismic vessels can be found in Appendix B (e).

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this for marine mammals exposed to airgun pulses. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Those criteria have been used in defining the safety (=shutdown) radii planned for the 2004 Gulf of Mexico acoustical calibration study. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed in Appendix B (f) and summarized here,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary threshold shift (TTS) let alone permanent auditory injury, at least for delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS).
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airgun array (and multibeam sonar), and to avoid exposing them to sound pulses that might cause hearing impairment (see § XI, MITIGATION MEASURES). In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002). Given the available data, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 μPa rms (approx. 221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the

TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m (328 ft) around a seismic vessel.

There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale.

TTS thresholds for pinnipeds exposed to brief pulses (single or multiple) have not been measured. However, prolonged exposures show that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999; Ketten et al. 2001; *cf.* Au et al. 2000).

A marine mammal within a radius of ≤100 m (≤328 ft) around a typical array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel. As noted above, most cetaceans show some degree of avoidance of operating airguns. In addition, ramping up airgun arrays, which is standard operational protocol for L-DEO, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. However, TTS would be more likely in any odontocetes that bow-ride or otherwise linger near the airguns. While bow-riding, odontocetes would be at or above the surface, and thus not exposed to strong sound pulses given the pressure-release effect at the surface. However, bow-riding animals generally dive below the surface intermittently. If they did so while bow-riding near airguns, they would be exposed to strong sound pulses, possibly repeatedly. If some cetaceans did incur TTS through exposure to airgun sounds, this would very likely be a temporary and reversible phenomenon.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 μPa (rms). The predicted 180 and 190 dB distances for the airgun arrays operated by L-DEO are summarized in § I. These sound levels are ***not*** considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, TTS data that are now available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 μPa rms.

Permanent Threshold Shift (PTS).—When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, while in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level 20 dB or more above that inducing mild TTS if the animal were exposed to the strong sound for an extended period, or to a strong sound with rather rapid rise time—see Appendix B (f).

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, and pinnipeds are unlikely to be encountered during the present project. Furthermore, the planned monitoring and mitigation measures, including visual monitoring, ramp-ups, and power-downs of the airguns when mammals are seen within the “safety radii”, will minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects.—Non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in marine mammals exposed to sound from airgun arrays, but there have been no direct studies of the potential for airgun pulses to elicit any of these effects. If any such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods.

It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop, at least in the case of the present project when operations at a given site would be limited to 1–2 days.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at this frequency, the ensuing resonance could cause damage to the animal. A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. However, a short paper concerning beaked whales stranded in the Canary Islands in 2002 suggests that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, this might occur if they ascend unusually quickly when exposed to aversive sounds.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects. Also, the planned mitigation measures (§ XI), including ramp-ups and power-downs, will reduce the possibility of any such effects.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding. However, the association of mass strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. Appendix B (g) provides additional details.

Seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2 to 10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (NOAA and USN 2001; Jepson et al. 2003), even if only indirectly, suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-gun 8490-in^3 array in the general area. The link between this stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). Nonetheless, this plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(b) Possible Effects of Bathymetric Sonar Signals

A multibeam bathymetric sonar (Atlas Hydrosweep DS-2, 15.5-kHz) will be operated from the source vessel during much of the planned study. In addition, a 12 kHz depth recorder will be operated from the ship during the sonar calibration portion of the 2004 study. Details about this equipment were provided in Section I. Sounds from the multibeam sonar are very short pulses, occurring for 1–10 ms once every 1 to 15 s, depending on water depth. Most of the energy in the sound pulses emitted by this multibeam sonar is at high frequencies, centered at 15.5 kHz. The beam is narrow (2.67º) in fore–aft extent, and wide (140º) in the cross-track extent. Each ping consists of five successive transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the five segments, i.e. for 1/5th or at most 2/5th of the 1–10 ms.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Atlas Hydrosweep, (2) have a longer pulse duration, and (3) are directed close to horizontally, vs. downward for the Hydrosweep. The area of possible influence of the Hydrosweep is much smaller—a narrow band below the source vessel. Marine mammals that encounter the Hydrosweep at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses.

Masking

Marine mammal communications will not be masked appreciably by the multibeam sonar signals given the low duty cycle of the sonar and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. However, all of these observations are of limited relevance to the present situation. Pulse durations from these sonars were much longer than those of the L-DEO multibeam sonar, and a given mammal would have received many pulses from the naval sonars. During L-DEO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 s pulsed sounds at frequencies similar to those that will be emitted by the multibeam sonar used by L-DEO, and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002). The relevance of these data to free-ranging odontocetes is uncertain, and in any case the test sounds were quite different in either duration or bandwidth as compared with those from a bathymetric sonar.

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the *Ewing*'s multibeam sonar. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the bathymetric sonar sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals. Also, in the present project, it is very unlikely that any pinnipeds will be encountered.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the multibeam bathymetric sonar system would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the multibeam sonar proposed for use by L-DEO is quite different than sonars used for navy operations. Pulse duration of the multibeam sonar is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the multibeam sonar for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally-directed sound.) These factors would all reduce the sound energy received from the multibeam sonar rather drastically relative to that from the sonars used by the Navy.

(c) Possible Effects of Sub-bottom Profiler Signals

A sub-bottom profiler will be operated from the source vessel at some times during the planned study. Details about this equipment were provided in § I. Sounds from the sub-bottom profiler are very short pulses, occurring for 1, 2 or 4 ms once every second. Most of the energy in the sound pulses emitted by this sub-bottom profiler is at mid frequencies, centered at 3.5 kHz. The beamwidth is ~30° and is directed downward.

Sound levels have not been measured directly for the sub-bottom profiler used by the *Ewing*, but Burgess and Lawson (2000) measured sounds propagating more or less horizontally from a similar unit with similar source output (205 dB re 1 μPa·m). The 160 and 180 dB re 1 μPa rms radii, in the horizontal direction, were estimated to be, respectively, near 20 m (66 ft) and 8 m (26 ft) from the source, as measured in 13 m or 43 ft water depth. The corresponding distances for an animal in the beam below the transducer would be greater, on the order of 180 m (591 ft) and 18 m (59 ft), assuming spherical spreading.

The sub-bottom profiler on the *Ewing* has a stated maximum source level of 204 dB re 1 μPa · m (see § I). Thus the received level would be expected to decrease to 160 and 180 dB about 160 m (525 ft) and 16 m (52 ft) below the transducer, respectively, again assuming spherical spreading. Corresponding distances in the horizontal plane would be lower, given the directionality of this source (30° beamwidth) and the measurements of Burgess and Lawson (2000).

Masking

Marine mammal communications will not be masked appreciably by the sub-bottom profiler signals given its relatively low power output, the low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the sub-bottom profiler are much weaker than those from the airgun array and the multibeam sonar. Therefore, behavioral responses are not expected unless marine mammals are very close to the source, e.g., with about 160 m (525 ft) below the vessel, or a lesser distance to the side.

NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a “take” by harassment.

Hearing Impairment and Other Physical Effects

Source levels of the sub-bottom profiler are much lower than those of the airguns and the multibeam sonar, which are discussed above. Sound levels from a sub-bottom profiler similar to the one on the *Ewing* were estimated to decrease to 180 dB re 1 μPa (rms) at 8 m or 26 ft horizontally from the source (Burgess and Lawson 2000), and at ~18 m downward from the source. Furthermore, received levels of pulsed sounds that are necessary to cause temporary or especially permanent hearing impairment in marine mammals appear to be higher than 180 dB (see earlier). Thus, it is unlikely that the sub-bottom profiler produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source.

The sub-bottom profiler is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the less intense sounds from the sub-bottom profiler. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of the higher-power sources (see § XI) would further reduce or eliminate any minor effects of the sub-bottom profiler.

(d) Numbers of Marine Mammals that Might be "Taken by Harassment"

All anticipated takes would be "takes by harassment" as described in § V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. In the sections below we describe methods to estimate "take by harassment" and present estimates of the numbers that might be affected during the proposed study in the northern Gulf of Mexico. These estimates are based on data concerning marine mammal densities (numbers per unit area) in the northern Gulf of Mexico, and estimates of the areas where effects could potentially occur.

This section provides two types of estimates: estimates of the number of potential "exposures", and estimates of the number of different individual mammals that might potentially be exposed to sound levels ≥160 and/or ≥170 dB re 1 μPa (rms). The ≥170 dB criterion is applied for delphinids only. The distinction between "exposures" and "number of different individuals exposed" is important in this project because the plan calls for repeated airgun operations through the same waters. Specifically, the project proposes to survey each of three survey lines six times, as described in § I. If many marine mammals are present near any of these lines, then many of the same individual mammals are likely to be approached by the operating airguns on more than one occasion. In addition, any animals that react to distant seismic sounds by moving away from the source are not likely to be present and affected during the second and subsequent surveys of any given line. This distinction between the number of *exposures* and the number of *different individuals exposed* has been recognized in estimating numbers of "takes" during some previous seismic surveys conducted under IHAs (e.g., Harris et al. 2001; Moulton and Lawson 2002; LGL 2003d).

The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by operations with the 2 GI guns and the 6-, 10-, 12-, and standard and augmented 20-gun arrays planned to be used during the project. The anticipated radii of influence of the sonars and sub-bottom profiler are less than those for the airgun arrays (see above).

It is assumed that, during simultaneous operations of the multibeam sonar and airguns, any marine mammals close enough to be affected by the sonar would already be affected by the airguns. The sounds of the three sonar types (3.5, 12, and 15.5 kHz) are also proposed to be recorded separately while no airguns are operating, to obtain baseline data on associated sound propagation properties over a survey line distance of several kilometers each (see § I "*Multibeam Sonar and Sub-bottom Profiler*"). No animals are expected to exhibit more than short-term and inconsequential responses to these sources given their characteristics (e.g., narrow downward-directed beam) and other considerations described in § I and in subsections (b) and (c) above. Such reactions are not considered to constitute "taking" (NMFS 2001).

Basis for Estimating "Take by Harassment" for 2004 Gulf of Mexico Study

Extensive aircraft- and ship-based surveys have been conducted for marine mammals in the northern Gulf of Mexico (Mullin et al. 1991, 1994c; Davis and Fargion 1996; Mullin and Hoggard 2000; Würsig et al. 2000; Baumgartner et al. 2001; Davis et al. 2002; Fulling et al. 2003). The most comprehensive density data available for cetacean species in the northern Gulf of Mexico are from the 1996/97 GulfCet II surveys (Mullin and Hoggard 2000) and earlier related projects (Hansen et al. 1995; Davis and Fargion 1996).[2] However, oceanographic and other conditions strongly influence the distribution and

[2] Fulling et al. (2003) was not available to us in time for their density data, from continental shelf waters in the northern Gulf, to be used in the "take" calculations in this document. In any case, their data pertain to the late summer/early autumn period, whereas this study is to be done in April.

numbers of marine mammals present in an area (Davis et al. 2002). Thus, for some species the densities derived from recent surveys may not be representative of the densities that will be encountered during the proposed acoustical calibration study.

Table 3 gives the densities for each species or species group of marine mammals in our proposed study area based on 1996/97 GulfCet II surveys (Davis et al. 2000). These are the same densities used to estimate the number of marine mammals potentially affected during the 2003 Gulf of Mexico acoustical calibration study (LGL Ltd. 2003a,b,c). The densities from the GulfCet II studies had been corrected, by the original authors, for detectability bias associated with diminishing sightability with increasing lateral distance from the trackline [$f(0)$]. However, those densities had not been corrected for availability bias [$g(0)$], which is a measure of the probability of sighting an animal that is present along the survey trackline. In Table 3, we have adjusted the originally reported densities to account for availability bias. We used $g(0)$ values compiled from published and unpublished sources by Koski et al. (1998), as originally applied to ship survey data from southern California waters. Both $f(0)$ and $g(0)$ are specific to the survey vessel, the area where the surveys are being conducted, the sea state conditions during the survey, the species or species group, and to the observer(s) conducting the survey. Ideally, $f(0)$ and $g(0)$ values from one survey should not be used to "correct" density estimates from a different survey. However, $g(0)$ values specific to the surveys in the northern Gulf of Mexico were not available, and failure to apply some such corrections would result in severe underestimates of the numbers of some species that might be present and potentially affected. We attempted to use the "best available" data.

Potential Number of "Takes by Harassment" Based on "Exposures"

"Exposures" to ≥160 dB.—The potential number of occasions when members of each species might be exposed to received levels ≥160 dB re 1 μPa (rms) was calculated by multiplying

- its expected density, corrected as described above, times
- the anticipated total line-kilometers of operations with each of the six airgun configurations, times
- the cross-track distances within which received sound levels are predicted to be ≥160 dB.

For each airgun configuration, that cross track distance is 2x the predicted 160 dB radius, ranging from 2 x 0.51 km for the 2 GI guns to 2 x 9.2 km for the augmented 20-airgun array.

Based on this method, the anticipated total number of marine mammal *exposures* to seismic sounds ≥160 dB re 1 μPa (rms) is estimated to be 1960 (Table 3). Of these, 9 exposures to levels ≥160 dB are anticipated to involve endangered marine mammals (all nine would be sperm whales). The estimated total numbers of exposures of pantropical spotted dolphins, spinner dolphins, and clymene dolphins are 949, 229, and 206, respectively. Estimates for other species are lower (Table 3). For all delphinids combined, the total estimate is 1830.

The second column in Table 3, "*≥160 dB (Adjusted) / Requested Take Authorization*, shows somewhat higher estimates totalling 2209 marine mammals. ***These are the numbers for which "take authorization" is requested***. Some of the marine mammal species that are known or suspected to occur in the Gulf of Mexico were not recorded during the GulfCet surveys, or were recorded in very low numbers. The 2209 figure includes an adjustment for small numbers of balaenopterids and other species that might be encountered even though they were not recorded during the GulfCet surveys. It also includes adjustment for potentially increased numbers (5–100) of certain species that were observed infrequently during GulfCet but might be encountered in relatively large groups during the proposed activities. For these species, the mean observed group size during GulfCet surveys (Davis and Fargion 1996; Davis et al. 2000) was generally used to derive numbers for the "*Requested Take Authorization*" column.

TABLE 3. Estimates of the possible numbers of marine mammal exposures to specified sound levels, and the numbers of different individuals that might be exposed, during L-DEO's calibration study in the northern Gulf of Mexico in April 2004. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.

	Total Estimated No. of Exposures to a/				Total Estimated No. Individuals That May be Exposed to			
Species	**≥160 dB**	**≥160 dB (Adjusted)/ Requested "Take" Auth. [d]**	**≥170 dB (Delphinids Only)**	**≥170 dB (Adjusted, Delphinids Only) [d]**	**≥160**	**≥170 dB (Delphinids Only)**	**Abundance Estimate [g(0)] [bc]**	**Percent of Gulf of Mexico Population That May be Exposed to ≥160 dB [c]**
Physeteridae								
Sperm whale	*9*	***9***			*3*		459	*0.6*
Dwarf/Pygmy sperm whale	77	**77**			23		3871	0.6
Ziphiidae								
Cuvier's beaked whale	32	**32**			7		1607	1.5
Sowerby's beaked whale	4	**10**			0		NA	NA
Gervais' beaked whale	4	**10**			0		NA	NA
Blainville's beaked whale	4	**10**			0		NA	NA
Mesoplodon sp.					3		701	1.7
Unidentified Ziphiidae					2		NA	NA
Delphinidae								
Rough-toothed dolphin	9	**13**	3	13	3	1	465	0.6
Bottlenose dolphin	110	**110**	32	32	32	10	5561	0.6
Pantropical spotted dolphin	949	**949**	278	278	275	87	47848	0.6
Atlantic spotted dolphin	19	**23**	6	23	6	2	966	0.6
Spinner dolphin	229	**229**	67	100	66	21	11546	0.6
Clymene dolphin	206	**206**	60	100	60	19	10358	0.6
Striped dolphin	89	**100**	26	100	26	8	4496	0.6
Stenella spp.					1	0		
Short-beaked common dol	0	**5**	0	5	0	0	NA	NA
Long-beaked common dolp	0	**5**	0	5	0	0	NA	NA
Fraser's dolphin	5	**100**	2	100	2	0	106	1.5
Risso's dolphin	110	**110**	32	32	32	10	5561	0.6
Melon-headed whale	35	**100**	10	100	10	3	1738	0.6
Pygmy killer whale	6	**15**	2	15	2	1	313	0.6
False killer whale	29	**29**	9	10	9	3	1460	0.6
Killer whale	2	**11**	1	11	1	0	122	0.6
Peponocephala/Feresa	3	**3**	1	3	1	0	141	0.6
Short-finned pilot whale	29	**29**	9	16	9	3	1474	0.6
Long-finned pilot whale	0	**5**	0	5	0	0	NA	NA
Unidentified dolphin					12	4		
Unidentified odontocete					1	0		
Unidentified small whale					1	0		
Unidentified large whale					0	0		
Balaenopteridae								
North Atlantic right whale	*0*	***2***			0		*NA*	*NA*
Humpback whale	*0*	***2***			0		*NA*	*NA*
Minke whale	0	**2**			0		NA	NA
Bryde's whale	0	**5**			0		25	0.5
Sei whale	0	**2**			0		*NA*	*NA*
Fin whale	*0*	**2**			0		*NA*	*NA*
Blue whale	*0*	**2**			0		*NA*	*NA*

TABLE 3 (concluded).

Species	Total Estimated No. of Exposures to a/				Total Estimated No. Individuals That May be Exposed to			
	≥160 dB	≥160 dB (Adjusted)/ Requested "Take" Auth. [d]	≥170 dB (Delphinids Only)	≥170 dB (Adjusted, Delphinids Only) [d]	≥160	≥170 dB (Delphinids Only)	Abundance Estimate [g(0)] [bc]	Percent of Gulf of Mexico Population That May be Exposed to ≥160 dB [c]
Trichechidae								
West Indian manatee	*0*	***0***					*NA*	*NA*
Pinnipeds								
Hooded Seal	0	**2**					NA	NA

[a] The six proposed airgun configurations are the 20- (11,000 cu in), 20- (8575 cu in), 12-, 10-, and 6-airgun arrays and the 2 GI guns.

[b] Abundance estimates have been corrected for g(0) and partially identified species. These estimates are based on f(0)-corrected densities reported by Davis et al. (2000) and Hansen et al. (1995) (we also corrected their densities for g(0)).

[c] NA = Data not available, species status has not been assessed, or not applicable

[d] Adjusted numbers are based on mean group sizes for species not sighted or infrequently sighted during the GulfCet I (Davis and Fargion 1996) and GulfCet II surveys (Davis et al. 2000).

These estimates are based on 160 dB distances predicted from the acoustic model applied by L-DEO (see § I). Based on the preliminary 2003 empirical data for deep and shallow water, actual 160 dB distances in deep and shallow water are likely to be, respectively, less and more than predicted (L-DEO in prep.). No empirical acoustic data are available for intermediate depths, but it is reasonable to expect that they will be intermediate between those for deep and shallow water, and probably not greatly different from the predicted values. Given these considerations, the predicted numbers of marine mammals that might be exposed to ≥160 dB may be somewhat overestimated for species preferring deep water, and somewhat underestimated for those preferring shallow water (bottlenose dolphin, Atlantic spotted dolphin).

Delphinid Exposures to ≥170 dB.—The 160-dB criterion, on which the preceding estimates are based, was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix B (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB (rms). There is no generally accepted alternative "take" criterion for dolphins exposed to airgun sounds. However, if only those dolphins exposed to ≥170 dB re 1 µPa (rms) were, on average, affected sufficiently to be considered "taken by harassment", then the estimates of the numbers of exposures for the three most common species would be 278, 67, and 60, respectively. The total number of delphinid exposures to ≥170 dB is predicted to be 538. These values are based on the predicted 170 dB radii around each of the six array types (Table 1) and are considered to be more realistic estimates of the numbers of occasions when delphinids may be affected.

The fourth column in Table 3 ("*≥170 dB (Adjusted, Delphinids Only)*") shows the number of delphinid exposures, by species, with upward adjustments comparable to those applied in the ≥160 dB column. The fourth column indicates that there might be a total of 948 delphinid exposures to received levels ≥170 dB re 1 μPa.

Potential Number of Different Individuals That Might be "Taken"

The preceding text estimates the number of potential "takes" based on the number of *exposures*, whereas the following estimates the number of different *individual* mammals that might potentially be subjected to received levels of ≥160 dB and ≥170 dB re 1 μPa (rms) on one or more occasions. As noted earlier, the distinction is important in this project because there will be six repeated passes along more-or-less the same survey line at each of the three sites (shallow, slope and deep water). Thus, many of the same individual mammals are likely to be approached by the operating airguns on more than one occasion, and to come within the 160 dB distance, and perhaps the smaller 170 dB distance, more than once. This means that many of the mammals in the project area may be disturbed more than once, or that they may move away from the sound source during the first pass by the vessel and subsequently would not be approached during later passes. Thus, the total number of individuals likely to be disturbed one or more times is considerably lower than that calculated above based on the number of exposures.

To estimate the number of different individuals likely to be exposed to ≥160 dB or ≥170 dB re 1 μPa (rms) on one or more occasions, we estimate the number that would be exposed during the *one* pass at each site when the strongest sound source is operating. This number was estimated assuming 128 line-kilometers of operations by the largest airgun array. That figure was multiplied by 2× the predicted 160 or 170 dB re 1 μPa rms radius (9.2 or 2.9 km) for the augmented 20-airgun array, and by the corrected marine mammal densities.

Based on this approach and the 160 dB criterion, the number of *individual* mammals that may be exposed to sounds ≥160 dB re 1 μPa (rms) is 587. This includes an estimated three endangered individuals, all sperm whales, and 549 delphinids (Table 3). Based on the 170 dB criterion, the corresponding figure for individual *delphinids* is 172. In descending order, the most common delphinid species, and the estimated numbers that might receive airgun pulses with levels ≥170 dB re 1 μPa rms on one or more occasions, are as follows: pantropical spotted dolphins, approx. 87, spinner dolphins, ~21, and clymene dolphins, ~19 (Table 3). Estimates for other species are lower.

The above estimates could underestimate the actual number of different individuals exposed to ≥160 or ≥170 dB on one or more occasions. The L-DEO spar buoy will drift by some unknown amount, and each of the ~6 survey lines at a given site will pass within ~100 m of that buoy. Assuming that the drifting spar buoy and not a bottom-moored unit will be the primary receiving system, the locations of the six "repeated" lines at each site will vary somewhat as a function of the drift rate of the spar buoy. In addition, the orientations of the six lines past the drifting buoy may change somewhat from one pass to the next. If the drift rate is high enough, or the orientation of the six lines at a given site varies, the total area exposed to ≥160 dB or ≥170 dB during operations along the six lines could somewhat exceed the area exposed during operations with the augmented 20-gun array. Also, some of the marine mammals may travel appreciable distances during the time required to complete the six survey lines at a given site, with some "new" mammals moving into the affected area from one pass to the next For these reasons, our estimates of the number of individuals potentially affected could be underestimates.

If the L-DEO spar buoy does not drift rapidly during the 2004 project, the actual numbers of individuals exposed to ≥160 or ≥170 dB on one or more occasions are likely to be better approximated by these estimates than by the corresponding estimated numbers of exposures. However, if the buoy drifts rapidly, as it did during the 2003 acoustic calibration project, there might be little overlap in the areas exposed to ≥160 dB (or especially ≥170 dB) from one shot-line to the next. In that case, the individuals encountered along the various shot lines would be predominantly different, and the total number of individuals exposed could be almost as large as the calculated number of exposures.

Pinnipeds are not expected to be encountered in the northern Gulf of Mexico, so it is very likely that the number of pinnipeds exposed to strong airgun sounds will 0. Nonetheless, L-DEO requests authorization to disturb as many as two pinnipeds (most likely hooded seals), in case extralimital individuals are encountered during the proposed survey.

Manatees are not the subject of this IHA Application to NMFS, since they are managed (in the U.S.A.) by the Fish & Wildlife Service. Also, it is unlikely that manatees would be taken by harassment, since manatees rarely occur even in the shallowest water where project activities are expected to occur (~30 m).

(e) Conclusions

The proposed acoustic calibration project will involve towing an airgun array that introduces pulsed sounds into the ocean, along with simultaneous operation of a multibeam sonar and sub-bottom profilers. A spar buoy with receiving electronics and radio-telemetry equipment will be used to receive airgun sounds at distances from 100 m to about 10–15 km. Some of the work will be conducted with a relatively small sound source consisting of 2 GI guns with total air volume 210 in^3. The remainder of the work will employ a variety of airgun configurations more similar to those used for typical high-energy seismic surveys, but with varying numbers of airguns (6, 10, 12 or 20) firing at any given time. Total gun volumes for the shots involving 6–12 airguns will be 1350–3755 in^3. Total volumes for the standard and augmented 20-gun arrays will be 8600 and 11,000 in^3, both of which are relatively large volumes but not an unusually large number of airguns. (The number of airguns has a more direct effect on total sound output than does the total array volume.) Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with operations of the three sonar types given the considerations discussed in § I and § VII (b), i.e., sonar sounds are beamed downward, the beam is narrow, the pulses are extremely short, etc.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km (3.2–4.3 n.mi.) and occasionally as far as 20–30 km (10.8–16.2 n.mi.) from the source vessel. However, reactions at the longer distances appear to be atypical of most species and situations. Furthermore, mysticetes are unlikely to be encountered during the planned 2004 study in the Gulf of Mexico, and if they are encountered, the numbers are expected to be low.

Odontocete reactions to seismic pulses, or at least the reactions of dolphins, are expected to extend to lesser distances than are those of mysticetes. Odontocete low-frequency hearing is less sensitive than that of mysticetes, and dolphins are often seen from seismic vessels. In fact, there are documented instances of dolphins approaching active seismic vessels. However, dolphins as well as some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels

Taking into account the mitigation measures that are planned, effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are very low percentages of the population sizes in the Gulf of Mexico and the Northwest Atlantic generally, as described below.

Based on the 160 dB criterion, the number of *individual* mammals (n = 587) that would be exposed to sounds ≥160 dB re 1 μPa (rms) represent ~0.5 to 1.7% of the populations of each species in the Gulf of Mexico (Table 3). This includes an estimated three endangered individuals, all sperm whales, representing ~0.6% of the estimated (corrected) population of ~459 sperm whales in the Gulf of Mexico (Table 3). In the cases of mysticetes, beaked whales, and sperm whales, these potential reactions are expected to involve no more than very small numbers (0 to 7) of individual cetaceans. For these non-delphinid species, the estimated number of *exposures* of marine mammals to sounds ≥160 dB re 1 μPa (rms) represent ~2% of the populations of each species in the Gulf of Mexico (Table 3). Although it is most likely that no Brydes whales will be exposed to seismic sounds ≥160 dB re 1 μPa (rms) based on the reported (corrected) density of this species in the Gulf of Mexico, we request authorization to expose up to five individuals to ≥160 dB, given the possibility of encountering one or more groups of this non-listed species.

Larger numbers of delphinids may be affected by the proposed calibration study, but the population sizes of species likely to occur in the operating area are large, and the numbers potentially affected are small relative to the population sizes (Tables 2 and 3). The estimated number of *exposures of delphinids* to sounds ≥170 dB re 1 μPa (rms) represent ~0.003% of the ~165,000 dolphins estimated to occur in the Gulf of Mexico, and ~1.6 to 2% of the populations of each species occurring there (Table 3).

During the 2003 Gulf of Mexico calibration study, the "indirect" estimates of the numbers of individual marine mammals exposed to sound levels ≥160 dB included 47 pantropical spotted dolphins, 74 unidentified dolphins, 52 pygmy killer whales, and three unidentified large cetaceans (LGL Ltd. 2003c). These estimates were based on density estimates derived from sightings along 322 km of ship trackline when the airguns were not operating. Actual figures for 2004 are likely to be higher because the airguns will be operated for longer periods in 2004.

Varying estimates of the numbers of marine mammals that might be exposed to strong airgun sounds during the 2004 project have been presented, depending on the specific exposure criteria (≥160 vs. ≥170 dB) and calculation procedures (exposures vs. individuals). The actual numbers of marine mammals that may be exposed to these noise levels are most likely to be somewhere between the estimated numbers of exposures and the estimated numbers of individuals. The requested numbers of authorized "takes" are based on the estimated numbers of exposures to ≥160 dB re 1 μPa (rms), and likely overestimate the actual numbers of animals that will be exposed to these sounds. However, even these estimates are quite low percentages of the population sizes. Also, these relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

The many cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as controlled speed, course alternation, look-outs, non-pursuit, ramp-ups, and power-downs when marine mammals are seen within defined ranges should further reduce short-term reactions, and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds and Sirenians

No pinnipeds are expected to be encountered in the Gulf of Mexico and thus it is most likely that none will be affected by the proposed measurements of airgun and sonar sounds. At most, up to two extralimital hooded seals might be encountered.

Manatees are not the subject of this IHA Application to NMFS, since they are managed (in the U.S.A.) by the Fish & Wildlife Service. However, it is unlikely that manatees would be affected by the planned airgun or sonar operations. Manatees are rare in waters deep enough for operations by a seismic survey vessel of the type to be used in this project. West Indian manatees are found in shallow estuarine and coastal waters of the northeastern Gulf of Mexico. The proposed airgun operations are expected to be in the north-central Gulf of Mexico, and in waters at least 30 m deep. Thus, manatees are not expected to occur near the proposed activities. Even if they did occur near the proposed activities, it is unlikely that there would be more than short-term effects on their behavior or distribution.

VIII. ANTICIPATED IMPACT ON SUBSISTENCE

The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

There is no subsistence hunting for marine mammals in the Gulf of Mexico, so the proposed activities will not have any impact on the availability of the species or stocks for subsistence users.

IX. ANTICIPATED IMPACT ON HABITAT

The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

The proposed acoustical calibration of airguns project will not result in any permanent impact on habitats used by marine mammals, or to the food sources they utilize. The main impact issue associated with the proposed activity will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed in Sections VI/VII, above.

The actual area contacted temporarily by the bottom-moored buoy, if it is used, will be an insignificant and very small fraction of the marine mammal habitat and the habitat of their food species in the area. The use of this buoy would result in no more than a negligible and highly localized short-term disturbance to sediments and benthic organisms. The area that might be disturbed is a very small fraction of the overall area.

One of the reasons for the adoption of airguns as the standard energy source for marine seismic surveys was that they (unlike the explosives used in the distant past) do not result in any appreciable fish kill. Various experimental studies showed that airgun discharges cause little or no fish kill, and that any injurious effects were generally limited to the water within a meter or so of an airgun. However, it has recently been found that injurious effects on captive fish, especially on fish hearing, may occur to somewhat greater distances than previously thought (McCauley et al. 2000a,b, 2002; 2003). Even so, any injurious effects on fish would be limited to short distances. Also, many of the fish that might otherwise be within the injury-radius are likely to be displaced from this region prior to the approach of the airguns through avoidance reactions to the passing seismic vessel or to the airgun sounds as received at distances beyond the injury radius.

Short, sharp sounds can cause overt or subtle changes in fish behavior. Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the field to an airgun. When the airgun was discharged, the fish dove from 25 to 55 m (80–180 ft) depth and formed a compact layer. By the end of an hour of exposure to the sound pulses, the fish had habituated; they rose in the water despite the continued presence of the sound pulses. However, they began to descend again when the airgun resumed firing after it had stopped. The whiting dove when received sound levels were higher than 178 dB re 1 µPa (peak pressure[3]) (Pearson et al. 1992).

Pearson et al. (1992) conducted a controlled experiment to determine effects of strong noise pulses on several species of rockfish off the California coast. They used an airgun with a source level of 223 dB re 1 µPa. They noted

- startle responses at received levels of 200–205 dB re 1 µPa (peak pressure) and above for two sensitive species, but not for two other species exposed to levels up to 207 dB;
- alarm responses at 177–180 dB (peak) for the two sensitive species, and at 186 to 199 dB for other species;
- an overall threshold for the above behavioral response at about 180 dB (peak pressure);
- an extrapolated threshold of about 161 dB (peak) for subtle changes in the behavior of rockfish; and
- a return to pre-exposure behaviors within the 20–60 min exposure period.

In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted (Dalen and Raknes 1985; Dalen and Knutsen 1986; Skalski et al. 1992). Reductions in the catch may have resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased. In the Barents Sea abundance of cod and haddock measured acoustically was reduced by 44% within 9.2 km (5.0 n.mi.) of an area where airguns operated (Engås et al. 1993). Actual catches declined by 50% throughout the trial area and 70% within the shooting area. This reduction in catch decreased with increasing distance to 30–33 km (16.2–17.8 n.mi.) where catches were unchanged.

Other recent work concerning behavioral reactions of fish to seismic surveys, and concerning effects of seismic surveys on fishing success, is reviewed in Turnpenny and Nedwell (1994), Santulli et

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[3] For airgun pulses, root-mean-square (rms) pressures, averaged over the pulse duration, are on the order of 10–13 dB less than peak pressure (Greene 1997; McCauley et al. 1998, 2000b).

al. (1999), Hirst and Rodhouse (2000), Thomson et al. (2001), Wardle et al. (2001), and Engås and Løkkeborg (2002).

In summary, fish often react to sounds, especially strong and/or intermittent sounds of low frequency. Sound pulses at received levels of 160 dB re 1 µPa (peak) may cause subtle changes in behavior. Pulses at levels of 180 dB (peak) may cause noticeable changes in behavior (Chapman and Hawkins 1969; Pearson et al. 1992; Skalski et al. 1992). It also appears that fish often habituate to repeated strong sounds rather rapidly, on time scales of minutes to an hour. However, the habituation does not endure, and resumption of the disturbing activity may again elicit disturbance responses from the same fish.

Fish near the airguns are likely to dive or exhibit some other kind of behavioral response. This might have short-term impacts on the ability of cetaceans to feed near the survey area. However, only a small fraction of the available habitat would be ensonified at any given time, and fish species would return to their pre-disturbance behavior once the seismic activity ceased. Thus, the proposed surveys would have little impact on the abilities of marine mammals to feed in the area where seismic work is planned. Some of the fish that do not avoid the approaching airguns (probably a small number) may be subject to auditory or other injuries.

Zooplankters that are very close to the source may react to the shock wave. These animals have an exoskeleton and no air sacs. Little or no mortality is expected. Many crustaceans can make sounds and some crustacea and other invertebrates have some type of sound receptor. However, the reactions of zooplankters to sound are not known. Some mysticetes feed on concentrations of zooplankton. A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused a concentration of zooplankton to scatter. Pressure changes of sufficient magnitude to cause this type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible, and this would translate into negligible impacts on feeding mysticetes. In the present project area, mysticetes are expected to be rare.

Because of the reasons noted above, the operations are not expected to cause significant impacts on habitats used by marine mammals, or on the food sources that marine mammals utilize.

X. Anticipated Impact of Loss or Modification of Habitat on Marine Mammals

The anticipated impact of the loss or modification of the habitat on the marine mammal populations involved.

The effects of the planned activity on marine mammal habitats and food resources are expected to be negligible, as described above. A small minority of the marine mammals that are present near the proposed activity may be temporarily displaced as much as a few kilometers by the planned activity. Areas with concentrations of marine mammals will be avoided when specific study sites are selected immediately before the start of acoustic measurement activities in deep, intermediate and shallow regions. In this manner, any major feeding or calving area that might occur in the general vicinity of the project will be avoided. Therefore, the proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations.

XI. MITIGATION MEASURES

The availability and feasibility (economic and technological) of equipment, methods, and manner of conducting such activity or other means of effecting the least practicable adverse impact upon the affected species or stocks, their habitat, and on their availability for subsistence uses, paying particular attention to rookeries, mating grounds, and areas of similar significance.

One of the main purposes of the acoustical measurements to be made during the 2004 Gulf of Mexico project is to further verify and refine modeled safety radii for the various airgun arrays proposed to be used during future L-DEO seismic studies in 2004 and later. The project will provide additional data on the sounds from the five airgun configurations studied in 2003. The project will also provide data on other sources whose sounds were not studied in 2003, specifically the augmented 20-gun array and the 3.5, 12, and 15.5 kHz sonars. The sound pressure fields estimated by a model are currently being compared with measurements of actual sound pressure levels measured in 2003 (L-DEO in prep.). The results of these analyses will be available during autumn 2003, and will be used to refine the safety radii proposed in this IHA application. Current NMFS practice is to define the safety ("shutdown") radii for cetaceans and pinnipeds based on the distances within which received levels may exceed, respectively, 180 and 190 dB re 1 μPa rms (NMFS 2000).

For the proposed airgun calibration work in the Gulf of Mexico in 2004, L-DEO will use 2 GI guns with total volume 210 in^3, a standard 20-gun array with a varying number of active guns (6–20 guns; total volume 1350–8600 in^3), and an augmented 20-gun array with total volume 11,000 in^3. Individual airguns will range in size from 80 to 875 in^3. The airguns in the 6–20 gun arrays will be spread out horizontally so the energy from the array will be directed mostly downward. The directional nature of the arrays to be used in this project is an important mitigating factor. This directionality will result in reduced sound levels at any given horizontal distance as compared with the levels expected at that distance if the source were omnidirectional with the stated nominal source level. The modeled sound pressure fields of each of the six array configurations to be used in the Gulf of Mexico in 2004 are shown in Figures 7–12.

Mitigation and monitoring measures proposed to be implemented for the 2004 L-DEO acoustical calibration study have been developed and refined in cooperation with NMFS during previous 2003 L-DEO seismic studies and associated EAs, IHA applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for other L-DEO projects in 2003, plus additional mitigation and monitoring measures proposed by L-DEO. These measures are described in detail below.

The number of individual animals expected to be closely approached during the proposed activity will be small in relation to regional population sizes. With the proposed monitoring, ramp-up, and power-down provisions (see below), effects on those individuals are expected to be limited to behavioral disturbance. This is expected to have negligible impacts on the species and stocks.

Localized and temporally-variable areas of concentrated feeding or of special significance for marine mammals are known to occur within or near the planned area of operations during the season of operations. However, L-DEO will avoid conducting the proposed activities near important concentrations of marine mammals.

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activity.

Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all daytime airgun operations and during any nighttime start-ups of the airguns. These observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals are observed within, or about to enter, designated safety zones (see below) where there is a possibility of significant effects on hearing or other physical effects, airgun operations will be powered down.

- During daylight, vessel-based observers will watch for marine mammals near the seismic vessel during all periods with shooting (including ramp-ups), and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut-down.
- L-DEO proposes to conduct nighttime as well as daytime operations at the deep and shallow sites, but only daytime operations at the intermediate continental slope site (see § I). Observers dedicated to marine mammal observations will not be on duty during ongoing seismic operations at night. At night, bridge personnel will watch for marine mammals (insofar as practical at night) and will call for the airguns to be powered-down if marine mammals are observed in or about to enter the safety radii. If the airguns are ramped-up at night, two marine mammal observers will monitor marine mammals near the source vessel for 30 min prior to ramp-up using night vision devices.

The proposed monitoring plan is described in detail in § XIII.

Proposed Safety Radii

Based on an acoustic model applied by L-DEO, estimates of the 180 and 190 dB re 1 μPa (rms) distances for the six configurations of the airgun array proposed to be used for this project are shown in Table 1 (in § I). L-DEO may recommend refinements to some of these distances prior to the start of the 2004 Gulf of Mexico study. Those refinements would be based on the results of the acoustic measurements obtained by L-DEO in shallow and deep waters within the northern Gulf of Mexico from 27 May to 2 June 2003 (LGL Ltd. 2003c; L-DEO in prep.). Present indications are that actual 180 and 190 dB distances in deep water are somewhat less than the predicted values, whereas actual distances in shallow water are somewhat more than the predicted values. In the unexpected event that the modeled 180 and 190 dB radii have not been verified by empirical data at the time of the proposed project, precautionary (larger) safety radii, 1.5 times the modeled radii, will again be used, as done during L-DEO's 2003 projects.

Airguns will be powered-down immediately when cetaceans or pinnipeds are detected within or about to enter the appropriate 180-dB (rms) or 190-dB (rms) radius, respectively. The 180 and 190 dB criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. L-DEO is aware that NMFS is likely to release new noise-exposure guidelines soon. L-DEO will be prepared to revise its procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required by the new guidelines.

Mitigation During Operations

The following mitigation measures will be adopted during the proposed seismic program, provided that doing so will not compromise operational safety requirements:

1. Speed or course alteration;
2. Power-down procedures
3. Shut-down procedures; and
4. Ramp-up procedures.

Speed or Course Alteration

If a marine mammal is detected outside the safety radius and, based on its position and relative motion, is likely to enter the safety radius, the vessel's speed and/or course may be changed if this is practical while minimizing effects on planned science objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not approach within the safety radius. If the mammal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or power-down of the airguns.

Power-down Procedures

A power-down involves decreasing the number of airguns in use such that the radius of the 180-dB (or 190-dB) zone is decreased to the extent that marine mammals are not in the safety zone. A power-down may also occur when the vessel is moving from one seismic line to another. (However, during parts of this project, the full airgun array is planned to be operated during line changes—see § I.) During a power-down, one airgun will be operated. The continued operation of one airgun is intended to alert marine mammals to the presence of the seismic vessel in the area. In contrast, a shut-down occurs when all airgun activity is suspended.

If a marine mammal is detected outside the safety radius but is likely to enter the safety radius, and if the vessel's speed and/or course cannot be changed to avoid having the mammal enter the safety radius, the airguns will be powered-down before the mammal is within the safety radius. Likewise, if a mammal is already within the safety zone when first detected, the airguns will be powered-down immediately. During a power-down of the 20-gun array or any of its subsets involving 6, 10, or 12 guns, at least one airgun (e.g., 80 in^3) will be operated. If a marine mammal is detected within or near the smaller safety radius around that single airgun, all airguns will be shut down (see next subsection).

Following a power-down, airgun activity will not resume until the marine mammal has cleared the safety zone. The animal will be considered to have cleared the safety zone if it

- is visually observed to have left the safety zone, or
- has not been seen within the zone for 15 min in the case of small odontocetes and pinnipeds, or
- has not been seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales.

When airgun operations with a 6–20 gun array resume following a power-down whose duration has exeeded specified limits, the airgun array will be ramped up gradually. Ramp-up procedures are described below.

Shut-down Procedures

During a power-down, the operating airgun will be shut down if a marine mammal approaches within the modeled safety radius for the then-operating source, typically a single gun of 80 in^3. Since no calibration measurements have been done to confirm the modeled safety radii for the single gun, precautionary radii will be used (1.5 times the modeled safety radius). For an 80 in^3 airgun, the predicted 180-dB distance applicable to cetaceans is 36 m or 118 ft, and the x1.5 conservative radius is 54 m or 177 ft. The corresponding 190-dB radius applicable to pinnipeds is 13 m or 43 ft, with the x1.5 conservative radius being 20 m or 66 ft. If a marine mammal is detected within or about to enter the appropriate safety radius around the small source in use during a power-down, airgun operations will be entirely shut-down.

In that case, airgun activity will not resume until the marine mammal has cleared the safety zone. The animal will be considered to have cleared the safety zone if it is visually observed to have left the safety zone, or if it has not been seen within the zone for 15 min (small odontocetes and pinnipeds) or 30 min (mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales).

Ramp-up Procedures

A "ramp-up" procedure will be followed when the airgun array begins operating after a specified-duration period without airgun operations. Following the requirements under previous IHAs issued to L-DEO by NMFS, the specified period will vary depending on the speed of the source vessel and the size of the airgun array that is being used:

- Under normal operational conditions (vessel speed 4 knots or 7.4 km/h), the *Ewing* would travel 900 m (2953 ft) in ~7 min. The 900 m distance is the calculated 180 dB safety radius for the 8575 in^3 20-airgun array. A ramp-up would be required after a power-down or shut-down period lasting ~7 min or longer if the *Ewing* was traveling at 4 knots and was towing the 8575 in^3 20-airgun array.
- If the towing speed is reduced to 3 knots (5.6 km/h) or less, as sometimes required when maneuvering in shallow water, and the same 20-gun array is in use, a ramp-up would be required after a "no shooting" period lasting >10 min. At towing speeds not exceeding 3 knots, the source vessel would travel no more than 900 m (2953 ft) in ~10 min.
- Based on similar calculations, a ramp-up procedure would be required after ~6 min if the speed of the source vessel was 5 knots (9.3 km/h) while operating the same 20-gun array.
- During programs when a smaller (or larger) airgun array is being used, the specified period would be based on similar calculations using the time taken for the source vessel to travel to the boundary of the 180 dB safety zone for that array.

Ramp-up will begin with the smallest gun in the array (e.g., 80 in^3). Guns will be added in a sequence such that the source level of the array will increase in steps not exceeding 6 dB per 5-min period over a total duration of up to ~25 min in the case of the 20-gun arrays. During ramp-up, the safety zone for the full array will be maintained.

If the complete safety radius has not been visible for at least 30 min prior to the start of operations in either daylight or nighttime, ramp-up will not commence unless at least one airgun has been operating during the interruption of seismic survey operations. That airgun will have a source level of at least 180 dB re 1 μPa·m (rms). It is likely that the 6-, 10-, 12- and 20-airgun arrays will not be ramped up from a complete shut-down at night or in thick fog, since the outer part of the safety zone for these arrays will not be visible during those conditions. Presently available night vision devices used aboard the *Ewing* are not expected to be effective in detecting marine mammals at distances farther than ~200–250 m (LGL Ltd. 2003e). If one airgun has operated during a "power-down" period, ramp-up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals will be alerted to the approaching seismic vessel by the sounds from the single airgun and could move away if they choose.

Ramp-up of the airguns will not be initiated if a sea turtle or marine mammal is sighted within or near the applicable safety radii during the day or close to the vessel at night.

XII. PLAN OF COOPERATION

> Where the proposed activity would take place in or near a traditional Arctic subsistence hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses. A plan must include the following:
> (i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;
> (ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;
> (iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and
> (iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Not applicable. The proposed activity will take place in the Gulf of Mexico and no activities will take place in or near a traditional Arctic subsistence hunting area.

XIII. MONITORING AND REPORTING PLAN

> The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding...

L-DEO proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring, and to satisfy the anticipated monitoring requirements of the Incidental Harassment Authorization.

L-DEO's proposed Monitoring Plan is described below. L-DEO understands that this Monitoring Plan will be subject to review by NMFS, and that refinements may be required.

The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same regions. L-DEO is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

Vessel-based Visual Monitoring

At least two observers dedicated to marine mammal observations will be stationed aboard L-DEO's seismic survey vessel for the seismic 2004 acoustical calibration study in the Gulf of Mexico. At least one experienced marine mammal observer (MMO) with a minimum of one previous year of MMO experience will be on duty aboard the seismic vessel, along with at least one additional observer dedicated to marine mammal observations. Observers will be appointed by L-DEO with NMFS concurrence.

It is proposed that one or two MMOs aboard the seismic vessel will search for and observe marine mammals whenever airgun operations are in progress during daylight hours. When feasible, observations will also be made during daytime periods without airgun operations.

Two observers will be on duty for 30 min prior to the start of airgun operations after an extended shut-down and during ramp-ups. The 30-min observation period is only required prior to commencing seismic survey operations following a shut-down of the airgun array for more than 1 hr. After 30 min of observation, the ramp-up procedure will be followed.

If ramp-up procedures must be performed at night, two observers will be on duty starting at least 30 min prior to the start of airgun operations and continuing during the subsequent ramp-up procedures. Ramp-up procedures will not commence at night or during the day in poor visibility unless at least one airgun has been operating during the preceding interruption of seismic survey operations. Other than the specified periods mentioned above, no observers will be required to be on duty during seismic operations at night. However, L-DEO bridge personnel (port and starboard seamen and one mate) will assist in marine mammal observations whenever possible, and especially during operations at night, when designated marine mammal observers will not normally be on duty. At least one MMO will be on "standby" at night, in case bridge personnel see a marine mammal. Two image-intensifying night-vision devices (NVDs) will be available for use at night. These are ITT Industries Night Quest NQ220 "Night Vision Viewer" devices, equipped with a 3x magnification lens. The NQ220 is a Generation III binocular NVD.

If the airguns are powered-down, observers will continue to maintain watch to determine when the animal is outside the safety radius. Ramp-up of the airguns will occur after the observer has determined that the animal has cleared the safety zone. A mammal will be assumed to be clear of the safety zone it is visually observed to have left that zone, or if it has not been seen within the zone for 15 min (small odontocetes and pinnipeds) or 30 min (mysticetes and large odontocetes). For this purpose, "large odontocetes" will include sperm, pygmy sperm, dwarf sperm, and beaked whales.

Figures 13 and 14 summarize the decision-making sequence that will apply during daylight and darkness, respectively.

The observer(s) will watch for marine mammals from the highest practical vantagepoint on the vessel, which is either the bridge or the flying bridge. On the bridge of the *Ewing*, the observer's eye level will be 11 m (36 ft) above sea level, allowing for good visibility within a 210º arc. If observers are stationed on the flying bridge, the eye level will be 14.4 m (47.2 ft) above sea level. The observer(s) will systematically scan the area around the vessel with reticle binoculars (e.g., 7 × 50 Fujinon) and with the naked eye during the daytime. At night, night vision equipment will be available, if required. Laser rangefinding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation. (These are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to marine mammals directly.) If a marine mammal is seen well outside the safety radius, the vessel may be maneuvered to avoid having the mammal come within the safety radius (see Section XI, "Mitigation", above). When mammals are detected within or about to enter the designated safety radii, the airguns will be powered down immediately. The observer(s) will continue to maintain watch to determine when the animal is outside the safety radius. Airgun operations will not resume until the animal is observed to be outside the safety radius or until the specified intervals (15 or 30 min) have passed without a re-sighting.

The vessel-based monitoring will provide data required to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions, and thus to estimate the numbers of mammals potentially "taken" by harassment. It will also provide the information needed in order to shut down the airguns at times when mammals are present in or near the safety zone. When a mammal sighting is made, the following information about the sighting will be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to seismic vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel (shooting or not), sea state, visibility, cloud cover, and sun glare.

The data listed under (2) will also be recorded at the start and end of each observation watch and during a watch, whenever there is a change in one or more of the variables.

All mammal observations and airgun shutdowns will be recorded in a standardized format. Data will be entered into a custom database using a laptop computer when observers are off-duty. The accuracy of the data entry will be verified by computerized validity checks as the data are entered and by subsequent manual and computer checking of the database. These procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical or other programs for further processing and archiving.

Observers will be on duty in shifts of duration no longer than 4 hours. A second observer will also be on watch part of the time, including the 30-min periods preceding startup of the airguns and during ramp-ups. Use of two simultaneous observers will increase the proportion of the marine mammals present near the source vessel that are detected. Bridge personnel additional to the dedicated MMOs will also assist in detecting marine mammals and implementing mitigation requirements, and before the start of the seismic survey will be given instruction in how to do so.

Results from the vessel-based observations will provide

1. The basis for real-time mitigation (airgun power-down).
2. Information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS.
3. Data on the occurrence, distribution, and activities of marine mammals in the area where the acoustical calibration study is conducted.
4. Information to compare the distance and distribution of marine mammals relative to the source vessel at times with and without seismic activity.
5. Data on the behavior and movement patterns of marine mammals seen at times with and without seismic activity.

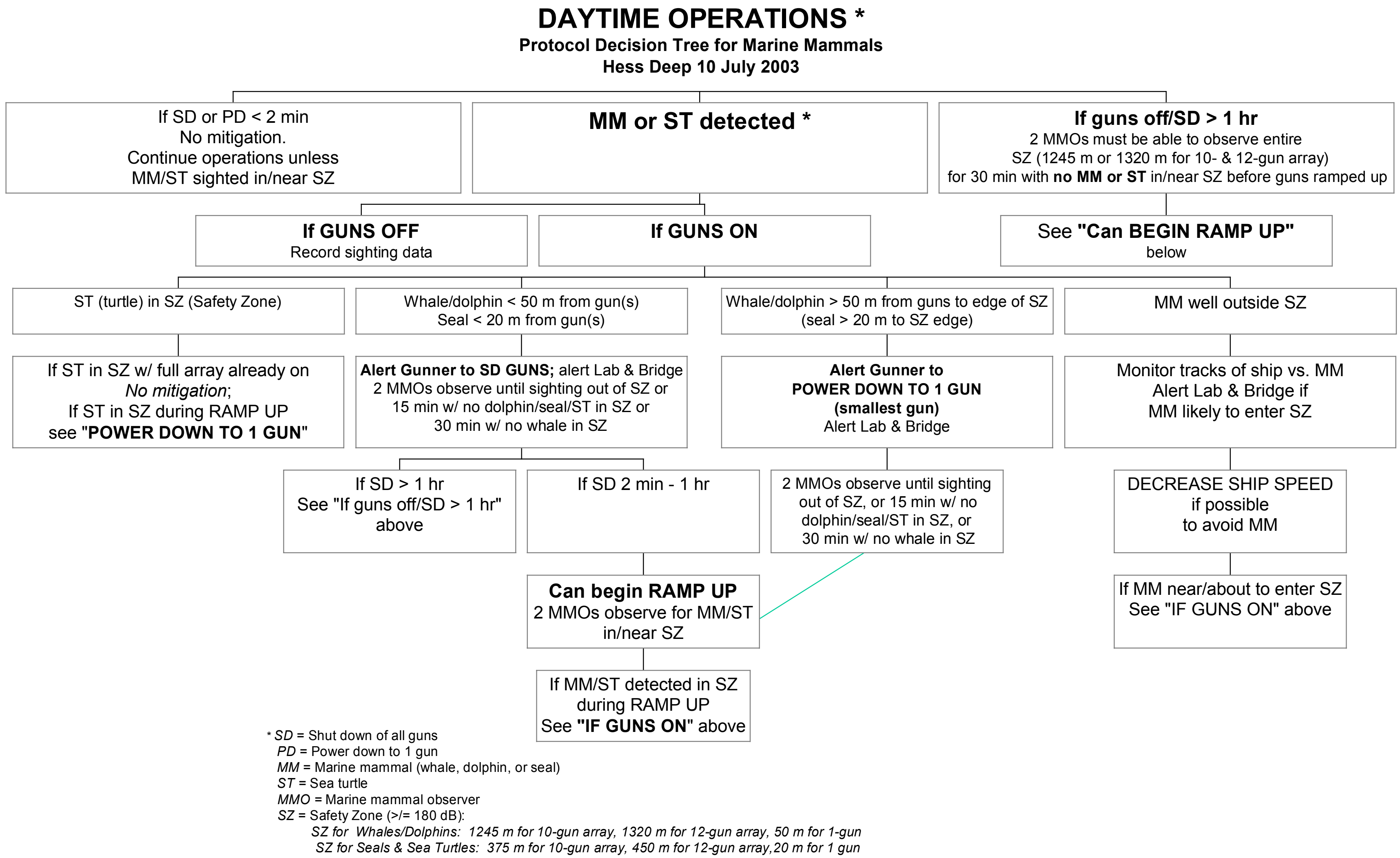

FIGURE 14. Flow diagram to aid in implementing ***daytime*** mitigation and monitoring required by the IHA. This version is one that was developed for L-DEO's July 2003 Hess Deep seismic study (LGL 2003d), and differs in some details from the anticipated requirements for the 2004 Gulf of Mexico project.

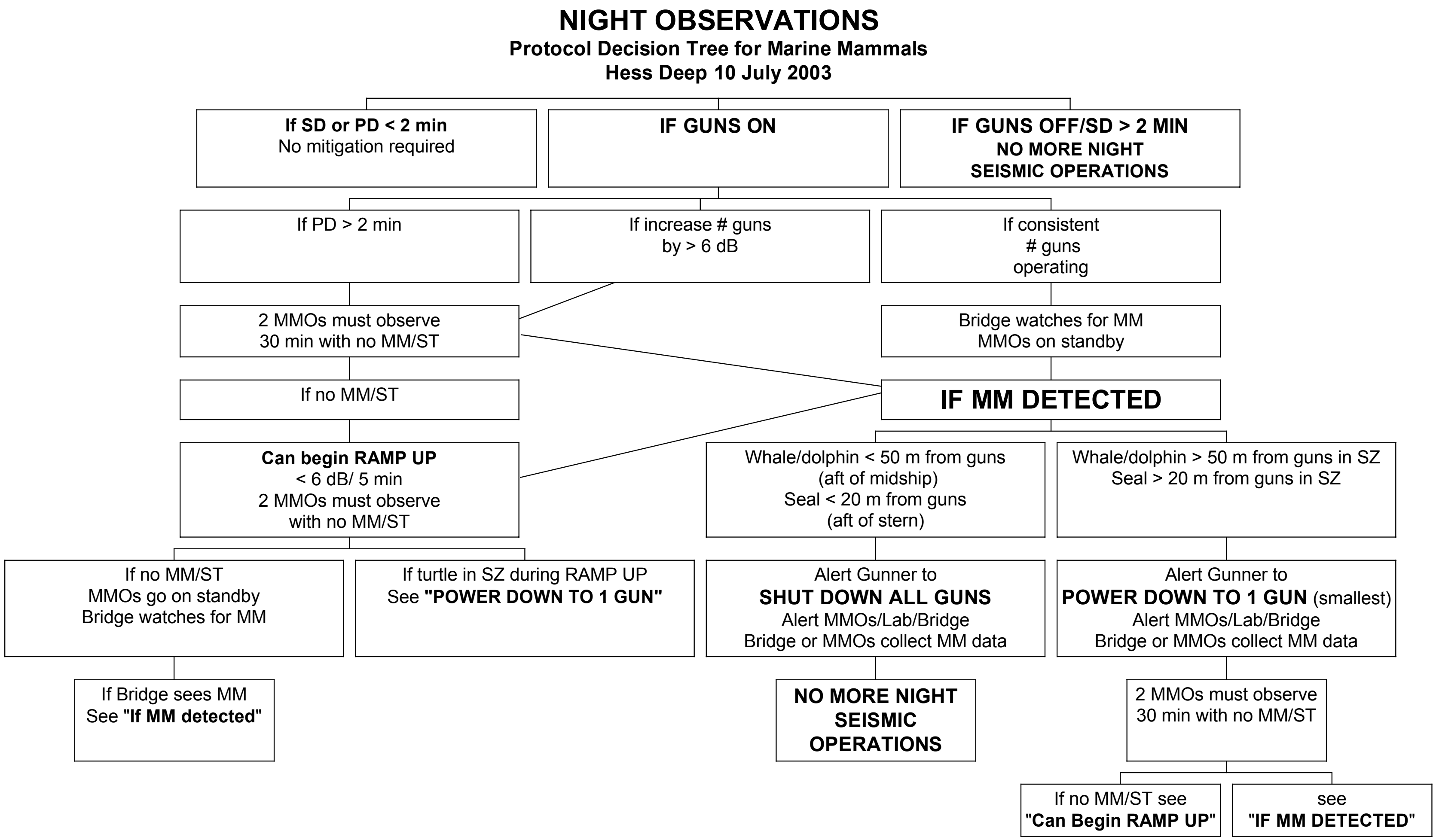

FIGURE 15. Flow diagram to aid in implementing ***nighttime*** mitigation and monitoring required by the IHA. This version is one that was developed for L-DEO's July 2003 Hess Deep seismic study (LGL 2003d), and differs in some details from the anticipated requirements for the 2004 Gulf of Mexico project.

Reporting

A report will be submitted to NMFS within 90 days after the end of the cruise. The end of this 2004 Gulf of Mexico acoustical calibration study is predicted to occur ~20 April 2004. The report will describe the operations that were conducted and the marine mammals that were detected near the operations. The report will be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all monitoring. The 90-day report will summarize the dates and locations of airgun operations, marine mammal sightings (dates, times, locations, activities, associated seismic survey activities), and estimates of the amount and nature of potential "take" of marine mammals by harassment or in other ways. Also included will be a summary of the acoustical measurement procedures that were applied and, if available within 90 days after the end of the cruise, a preliminary summary of the acoustical measurement results.

In the likely event that detailed acoustical results are not available within 90 days after the end of the cruise, a more complete account of those measurements will be submitted to NMFS at a later date.

XIV. Coordinating Research to Reduce and Evaluate Incidental Take

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

L-DOE will coordinate the planned project with other parties that may or are planning to sponsor, conduct or participate in marine mammal, acoustical, and oceanographic studies in the same region during the corresponding part of 2004. These groups could include NMFS, Minerals Management Service, NSF, U.S. Navy, the oil and seismic industry, Woods Hole Oceanographic Institution, Texas A & M University, University of New Orleans, and others.

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APPENDIX A:

MARINE MAMMAL AND SEA TURTLE SIGHTINGS DURING THE GULF OF MEXICO ACOUSTICAL CALIBRATION STUDY, 28 MAY – 2 JUNE 2003

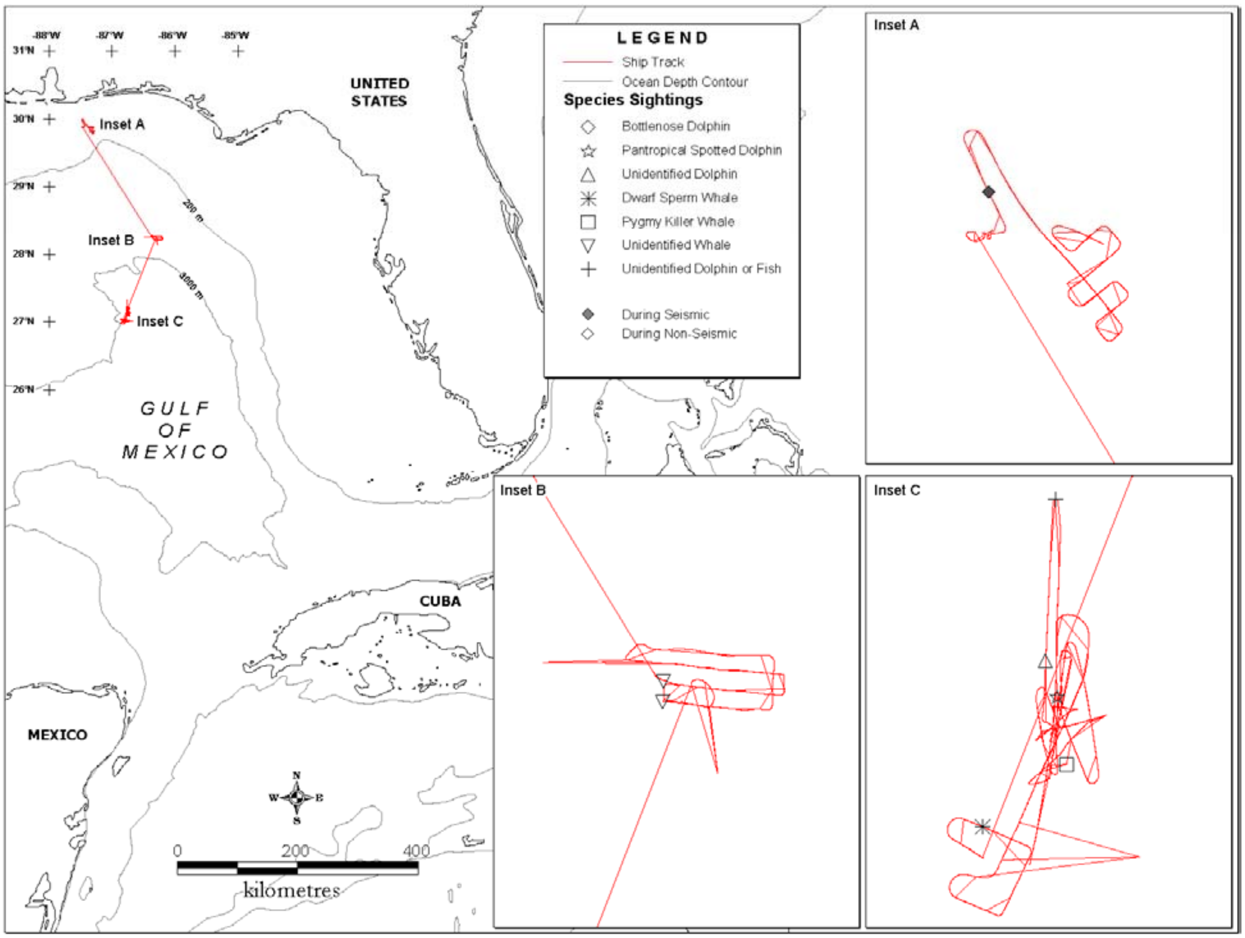

FIGURE A.1. Vessel survey tracks and marine mammal sightings during the 2003 acoustic calibration study by the *Ewing* in the northern Gulf of Mexico.

TABLE A.1. Numbers and species of marine mammals observed from the *Ewing*, 28 May – 2 June 2003. Distance and bearing are given relative to the observers' position on the flying bridge. Bearings are on a 1 to 12 o'clock scale, with 12 o'clock being directly ahead of the ship, 3 o'clock being 90° to starboard, 6 o'clock being directly astern, etc. From LGL Ltd. (2003c).

Species	Group Size	Date 2003	Local Time	Latitude (ºN)	Longitude (ºW)	Distance (m)	Bearing	Airgun Activity (No. Guns)	Beaufort Sea State	Visibility (km)	Approx. Water Depth (m)	Additional Species Sighting Information
Pygmy killer whale	10	28 May	18:31	27º04.06	86º44.42	1200	12	Off (0)	3	10	3200	Group included one calf
Unidentified dolphin or Fish	*12*	*May 29*	*15:23*	*27º18.16*	*86º45.09*	*2729*	*4*	*Off (0)*	*2*	*9*	3200	*Splashes in distance; either fish or dolphins*
Unidentified dolphin	7	29 May	14:30	27º09.56	86º45.63	3151	4	Off (0)	2	9	3200	Rough-toothed or bottlenose dolphins
Pantropical spotted dolphin	9	29 May	10:43	27º06.67	86º44.98	3200	10	Off (0)	3	10	3200	
Dwarf sperm whale	2	30 May	18:20	27º00.78	86º49.37	5000	11	On (20)	2	10	3200	Two *Kogia* sp. Probably *sima*
Unidentified whale	1	31 May	18:56	28º10.97	86º19.99	9000	11	Off (0)	3	10	500	Maybe sperm whale
Unidentified whale	1	1 June	06:51	28º12.35	86º19.95	10000	9	Off (0)	4	10	500	Probable large whale
Bottlenose dolphin	8	2 June	08:24	29º54.00	87º26.60	1125	12	On (2)	3	10	30	

TABLE A.2. Summary of sea turtle sightings from the *Ewing*, 28 May – 2 June 2003. Presented as in Table A.1.

Species	Group Size	Date 2003	Time (Local)	Latitude (ºN)	Longitude (ºW)	Distance from *Ewing* (m)	Seismic Activity (No. Guns)	Water Depth (m)	Movement	Pace	Initial Behavior / Second Behavior	Additional Species Sighting Information
Loggerhead sea turtle	1	28 May	18:00	27º05.43	86º44.14	1200	Off (0)	3200	-	-	-	Positively identified as loggerhead sea turtle.
Unidentified sea turtle	1	29 May	11:38	27º09.67	86º44.77	50	Off (0)	3200	Swam parallel to vessel	-	-	Swam below water surface
Loggerhead sea turtle	1	2 June	18:47	29º51.54	87º18.75	1200	On (20)	30	Swam away	Sedate	Swam/Dove	Shell of turtle sighted. Probably loggerhead sea turtle. Lifted head high and disappeared. Seen with big-eye binoculars.

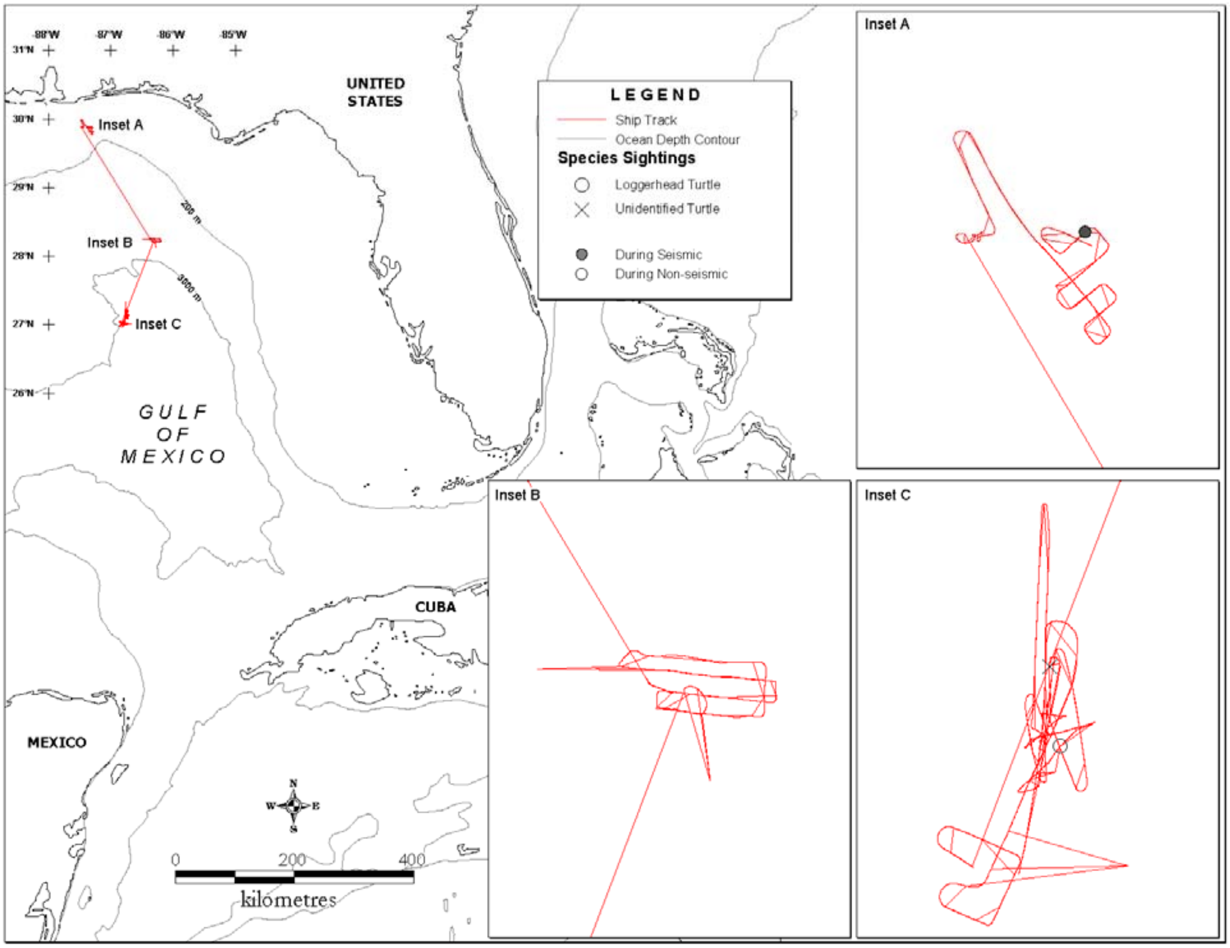

FIGURE A.2. Vessel survey tracks and sea turtle sightings during the 2003 acoustic calibration study by the *Ewing* in the northern Gulf of Mexico.

APPENDIX B:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [4]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § VI / VII of the IHA Application. This background material is little changed from corresponding subsections included in IHA Applications and EAs submitted to NMFS during 2003 for other L-DEO projects. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, and southern Gulf of Mexico (Yucatan Peninsula). Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

The effects of noise on marine mammals are highly variable, and can be categorized as follows (based on Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;

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[4] By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised November 2003.

6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

(b) Hearing Abilities of Marine Mammals

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise).
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to localize sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments also show that they hear and may react to many man-made sounds including sounds made during seismic exploration.

Toothed Whales

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are at present no specific data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales.

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, the sounds are sufficiently strong that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). However, there is no evidence that small odontocetes react to airgun pulses at such long distances, or even at intermediate distances where sound levels are well above the ambient noise level (see below).

The multibeam sonar operated from the *Ewing* emits pulsed sounds at 15.5 kHz. That frequency is within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multibeam sonar will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam.

Baleen Whales

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for a review). Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are almost certainly more sensitive to low-frequency sounds than are the ears of the small toothed whales. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or sonar) sounds would be detectable and yet often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson 2002).

Pinnipeds

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211*ff*; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, higher auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid (hair) seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to about 1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal (not an Atlantic/Gulf of Mexico species) appears to have better underwater sensitivity than the harbor seal, at least at low frequencies (Kastak and Schusterman 1998, 1999).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for hair seals (harbor or elephant seal).

The underwater hearing of a walrus has recently been measured at frequencies from 125 Hz to 15 kHz (Kastelein et al. 2002). The range of best hearing was from 1–12 kHz, with maximum sensitivity (67 dB re 1 µPa) occurring at 12 kHz (Kastelein et al. 2002).

Sirenians

The hearing of manatees is sensitive at frequencies below 3 kHz. A West Indian manatee that was tested using behavioral methods could apparently detect sounds from 15 Hz to 46 kHz (Gerstein et al. 1999). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral testing suggests their best sensitivity is at 6 to 20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

(c) Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10 to 20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain some energy up to 500–1000 Hz and above (Goold and Fish 1998). The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds to which whales and other marine mammals are routinely exposed. The only sources with higher or comparable effective source levels are explosions.

The peak-to-peak source levels of the 2- to 20-airgun arrays used by L-DEO during various projects range from 236 to 263 dB re 1 µPa at 1 m, considering the frequency band up to about 250 Hz. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

Several important mitigating factors need to be kept in mind. ***(1)*** Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for much longer durations than seismic pulses. ***(2)*** Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-target areas. ***(3)*** An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak levels, in bar-meters or dB re 1 µPa·m. The peak (= zero-to-peak) level for the same pulse is typically about 6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level over the duration of the pulse. The rms value for a given airgun pulse is typically about 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy level, in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse. Near the source, the predominant part of a seismic pulse is about 10 to 20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was about 300 ms at a distance of 8 km (4.3 n.mi.), 500 ms at 20 km (10.8 n.mi.), and 850 ms at 73 km or 39.4 n.mi. (Greene and Richardson 1988).

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995). Paired measurements of received airgun sounds at depths of 3 m (9.8 ft) vs. 9 m (29.5 ft) or 18 m (59 ft) have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m (1.6–3.3 ft) of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (L-DEO in prep.).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km (27–54 n.mi.) from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are low—below 120 dB re 1 μPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array.

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz and considerably lower spectrum levels above 1000 Hz. These low frequencies are mainly used by mysticetes, but generally not by odontocetes, pinnipeds, or sirenians. An industrial sound source will reduce the effective communication or echolocation distance only if its frequency is close to that of the marine mammal signal. If little or no overlap occurs between the industrial noise and the frequencies used, as in the case of many marine mammals vs. airgun sounds, communication and echolocation are not expected to be disrupted. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely even for mysticetes.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or possibly to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; Lesage et al. 1999; Terhune 1999; reviewed in Richardson et al. 1995:233*ff,* 364*ff*). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Disturbance is one of the main concerns in this project. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

There has been debate regarding how substantial a change in behavior or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has recently stated that

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do no disrupt the animal's overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization." (NMFS 2001, p. 9293).

Based on this guidance from NMFS, we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The definitions of "taking" in the U.S. Marine Mammal Protection Act, and its applicability to various activities, are presently (autumn 2003) under active consideration by the U.S. Congress. Some changes are likely. Also, the U.S. National Marine Fisheries Service is considering the adoption of new criteria concerning the noise exposures that are (and are not) expected to cause "takes" of various types. Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the main studies on this topic are the following: Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995, 1999; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000a; Miller et al. 1999.

Prior to the late 1990s, it was thought that bowhead whales, gray whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 μPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. Recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels somewhat lower than 160–170 dB re 1 μPa rms. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Humpback Whales.—McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with source level 227 dB re 1 μPa·m (p-p). They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single gun. Avoidance reactions began at 5–8 km (2.7–4.3 n.mi.) from the array and those reactions kept most pods about 3–4 km (1.6–2.2 n.mi.) from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km (7.6 n.mi.). Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5–8 km (2.7–4.3 n.mi.) from the airgun array and 2 km (1.1 n.mi.) from the single gun. However, some individual humpback whales, especially males, approached within distances 100–400 m (328–1312 ft), where the maximum received level was 179 dB re 1 μPa rms.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 μPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis.

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6 to 99 km (3–53 n.mi.) and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km or 1.6–3.8 n.mi.) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 μPa·m at a distance of 7.5 km (4 n.mi.), and swam away when it came within about 2 km (1.1 n.mi.). Some whales continued feeding until the vessel was 3 km (1.6 n.mi.) away. Feeding bowhead whales tend to tolerate higher sound levels than migrating whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. In 1996-98, a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km (10.8–16.2 n.mi.), and that few bowheads approached within 20 km (10.8 n.mi.). Received sound levels at those distances were only 116–135 dB re 1 μPa (rms). Some whales apparently began to deflect their migration path when still as much as 35 km (19 n.mi.) away from the airguns. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. These and other data suggest that migrating bowhead whales are more responsive to seismic pulses than were summering bowheads.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6 to 2.8 km (1.4–1.5 n.mi.) from an airgun array with a source level of 250 dB (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km (1.3 n.mi.) from a 4000-in^3 array operating off central

California (CPA = closest point of approach). This would occur at an average received sound level of about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (rms).

There was no indication that Western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001. However, there were indications of subtle behavioral effects and (in 2001) localized avoidance by some individuals (Johnson 2002; Weller et al. 2002).

***Rorquals*.**—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003). Baleen whale pods sighted from the ship were found to be at a median distance of about 1.6 km (0.9 n.mi.) from the array during shooting and 1.0 km (0.5 n.mi.) during periods without shooting (Stone 2003). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting (Stone 2003). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

***Discussion and Conclusions*.**—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, recent studies of humpback and especially migrating bowhead whales show that reactions, including avoidance, sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel are biased.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km (2.4–7.8 n.mi.) from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A in Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of humpback, bowhead and gray whales mentioned above. However, systematic work on sperm whales is underway.

Delphinids and Similar Species.—Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels. Authors reporting cases of small toothed whales close to the operating airguns have included Duncan (1985), Arnold (1996), and Stone (2003). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the guns were firing. However, in Puget Sound, Dall's porpoises observed when a 6000 in^3, 12–16-airgun array was firing tended to be heading away from the boat (Calambokidis and Osmek 1998).

Goold (1996a,b,c) studied the effects on common dolphins, *Delphinus delphis*, of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180-m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km (0.5 n.mi.) radius from the guns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

Observers stationed on seismic vessels operating off the United Kingdom from 1997–2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods of shooting. Except for pilot whales, all of the small odontocete species tested, including killer whales, were found to be significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales showed few reactions to seismic activity. The displacement of the median distance from the array was ~0.5 km (0.3 n.mi.) or more for most species groups. Killer whales also appear to be more tolerant of seismic shooting in deeper waters.

For all small odontocete species, except pilot whales, that were sighted during seismic surveys off the United Kingdom in 1997–2000, the numbers of positive interactions with the survey vessel (e.g., bow-riding, approaching the vessel, etc.) were significantly fewer during periods of shooting. All small odontocetes combined showed more negative interactions (e.g., avoidance) during periods of shooting. Small odontocetes, including white-beaked dolphins, *Lagenorhynchus* spp., and other dolphin spp. showed a tendency to swim faster during periods with seismic shooting; *Lagenorhynchus* spp. were also observed to swim more slowly during periods without shooting. Significantly fewer white-beaked dolphins, *Lagenorhynchus* spp., harbor porpoises, and pilot whales traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting.

Captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). Finneran et al. (2002) exposed a captive bottlenose dolphin and white whale to single impulses from a watergun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited a reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a white whale exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound (pk-pk level >200 dB re 1 µPa) before exhibiting the aversive behaviors mentioned above.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for TTS, the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Beaked Whales.—There are no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001). However, those vessels were not emitting airgun pulses.

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; see also the “Strandings and Mortality” subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There has been a recent (Sept. 2002) stranding of Cuvier’s beaked whales in the Gulf of California (Mexico) when the L-DEO vessel *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). This might be a first indication[5] that seismic surveys can have effects similar to those attributed to naval sonars. However, the evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km or 162 n.mi.) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, sperm whales in the Gulf of Mexico may have moved away from a seismic vessel (Mate et al. 1994).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 μPa pk-pk (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Tyack et al. in press), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate in press). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels up to 148 dB re 1 μPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Tyack et al. in press). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm. to LGL Ltd.); the broadband rms value would be somewhat higher. Although the sample size from the initial work was small (four whales during two experiments), the results are consistent with those off northern Norway.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may

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[5] It is quite unlikely that an earlier stranding of Cuvier's beaked whales in the Galapagos, during April 2000, was asociated with a then-ongoing seismic survey as "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry 2002).

strand after exposure to strong noise from sonars. Whether they ever do so in response to seismic survey noise is unknown.

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies in recent years. Monitoring studies in the Beaufort Sea during 1996-2001 provide a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Pinnipeds exposed to seismic surveys have also been observed during recent seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of seals exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, grey seals exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* G.D. Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong noise pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the United Kingdom, a radio-telemetry study has demonstrated short-term changes in the behavior of harbor (=common) seals and grey seals exposed to airgun pulses (Thompson et al. 1998). In this study, harbor seals were exposed to seismic pulses from a 90 in^3 array (3 × 30 in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km (1.3 n.mi.) from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m (1641 ft). All grey seals exposed to a single 10 in^3 airgun showed an avoidance reaction. Seals moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as all grey seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array." (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orient away whether or not the airguns were firing (Calambokidis and Osmek 1998).

Monitoring work in the Alaskan Beaufort Sea during 1996-2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6 to 16 airguns with total volumes 560 to 1500 in^3. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). However, these avoidance movements were relatively small, on the order of 100 m (328 ft) to (at most) a few hundreds of meters, and many seals remained within 100–200 m (328–656 ft) of the trackline as the operating airgun array passed by. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the array. The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g. "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Sirenians

Little information is available on the responses of manatees or dugongs to industrial noise sources and no information is available on the reactions of manatees to airgun noise. What information there is on manatee reactions to disturbance suggests that sirenians were disturbed by aircraft noise from a low (20–160 m) and slow (<20 km/h) helicopter (Rathbun 1988). However, many manatees exposed to boats and tourists are becoming tame, approaching both boats and people (Curtin and Tyson 1993). In Florida, more manatees are killed by collisions with boats than by any other known causes (O'Shea et al. 1985; Ackerman et al. 1989). Although manatees can apparently hear the sound frequencies emitted by outboard engines (Gerstein et al. 1999), manatees do not appear able to localize the direction from which the boat is traveling. Manatees often attempt to avoid oncoming boats by diving, turning, or swimming away, but their reaction is usually slow and does not begin until the boat is within 50–100 m, increasing the likelihood of collisions (Hartman 1979; Weigle et al. 1993). Although habituation of manatees to vessel travel has occurred in some areas, there is evidence of reduced use of some areas with chronic boat disturbance (Provancha and Provancha 1988). Winter aggregations in favored warm-water habitats can be dispersed by human activity.

In Queensland, dugongs in shallow (<2 m) water sometimes swim rapidly in response to motorboats up to 1 km away, often heading for deeper water even if that means swimming toward the vessel (Preen 1992). Dugongs in deeper water are less responsive, often diving several seconds before the boat arrives and resurfacing several seconds after it has passed.

It is unlikely that sirenians would be encountered in waters deep enough for a large seismic vessel to operate. They prefer water shallower and closer to shore than that where major seismic vessels normally operate.

(f) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shutdown) radii planned for numerous seismic surveys. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid Temporary Threshold Shift (TTS) let alone permanent auditory injury, at least for delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might cause hearing impairment. In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. The magnitude of TTS depends on the level and duration of noise exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

Toothed Whales.—Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTS generally became evident at received levels of 192 to 201 dB re 1 μPa rms at 3, 10, 20, and 75 kHz, with no strong relationship between frequency and onset of TTS across this range of frequencies. At 75 kHz, one dolphin exhibited TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited TTS after exposure to levels up to 193 dB

(Schlundt et al. 2000). There was no evidence of permanent hearing loss; all hearing thresholds returned to baseline values at the end of the study.

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1 to 13 milliseconds (ms) in duration and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure level) of 221 dB re 1 μPa produced no more than a slight and temporary reduction in hearing.

A similar study was conducted by Finneran et al. (2002) using an 80 in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). "Masked TTS" (MTTS) was observed in a beluga after exposure to a single impulse with peak-to-peak pressure of 226 dB re 1 μPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 $\mu Pa^2 \cdot s$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 μPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2000, 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds; the reference to masking (MTTS) refers to the fact that these measurements were obtained under conditions with substantial (but controlled) background noise. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 s or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With single short pulses, the TTS threshold appears to be (to a first approximation) a function of the energy content of the pulse (Finneran et al. 2002). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003). In particular, additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 μPa rms (approx. 221–226 dB pk-pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m (328 ft) around a seismic vessel.

Baleen Whales.—There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale.

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either single or multiple) have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels (rms) of ~178 and 183 dB re 1 μPa and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, prolonged exposures show that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations. For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure. Schusterman et al. (2000) showed that TTS thresholds of these seals were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. There are some indications that, for corresponding durations of sound, some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes (Kastak et al. 1999; Ketten et al. 2001; *cf*. Au et al. 2000).

Likelihood of Incurring TTS.—A marine mammal within a radius of ≤100 m (≤328 ft) around a typical array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel.

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. However, TTS would be more likely in any odontocetes that bow-ride or otherwise linger near the airguns. While bow-riding, odontocetes would be at or above the surface, and thus not exposed to strong sound pulses given the pressure-release effect at the surface. However, bow-riding animals generally dive below the surface intermittently. If they did so while bow-riding near airguns, they would be exposed to strong sound pulses, possibly repeatedly. If some cetaceans did incur TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are not as strong or consistent as those of cetaceans (see above). Pinnipeds occasionally seem to be attracted to operating seismic vessels. As previously noted, there are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. It is not known whether pinnipeds near operating seismic vessels, and especially those individuals that linger nearby, incur significant TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 μPa (rms). The corresponding limit for pinnipeds has been set at 190 dB. These sound levels are ***not*** considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 μPa rms.

It has been shown that most large whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. [Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp-up, when a single airgun is fired.] Thus, whales will likely not be exposed to high levels of airgun sounds. Likewise, any whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, while in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal. However, given the possibility that mammals close to an airgun array might incur TTS, there has been speculation about the possibility that some individuals occurring very close to airguns might incur TTS (Richardson et al. 1995, p. 372*ff*).

Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). For impulse sounds with very rapid rise times (e.g., those associated with explosions or gunfire), a received level not greatly in excess of the TTS threshold may start to elicit PTS. Rise times for airgun pulses are rapid, but less rapid than for explosions.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) has reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time.

Sound impulse duration, peak amplitude, rise time, and number of pulses are the main factors thought to determine the onset and extent of PTS. Based on existing data, Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 μPa (pk-pk) in odontocetes, then the PTS threshold might be as high as 240 dB re 1 μPa (pk-pk). In the units used by geophysicists, this is 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. Pinnipeds, on the other hand, often do not show strong avoidance of operating airguns.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales. Commonly-applied monitoring and mitigation measures, including visual monitoring, course alteration, ramp-ups, and power-downs of the airguns when mammals are seen within the "safety radii", would minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

(g) Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding. However, the association of mass strandings of beaked whales with naval exercises and, in a recent (2002) case, an L-DEO seismic survey, has raised the possibility that beaked whales may be especially susceptible to injury and/or behavioral reactions that can lead to stranding when exposed to strong pulsed sounds.

In March 2000, several beaked whales that had been exposed to repeated pulses from high intensity, mid-frequency military sonars stranded and died in the Providence Channels of the Bahamas Islands, and were subsequently found to have incurred cranial and ear damage (NOAA and USN 2001). Based on post-mortem analyses, it was concluded that an acoustic event caused hemorrhages in and near the auditory region of some beaked whales. These hemorrhages occurred before death. They would not necessarily have caused death or permanent hearing damage, but could have compromised hearing and navigational ability (NOAA and USN 2001). The researchers concluded that acoustic exposure caused this damage and triggered stranding, which resulted in overheating, cardiovascular collapse, and physiological shock that ultimately led to the death of the stranded beaked whales. During the event, five naval vessels used their AN/SQS-53C or -56 hull-mounted active sonars for a period of 16 h. The sonars produced narrow (<100 Hz) bandwidth signals at center frequencies of 2.6 and 3.3 kHz (-53C), and 6.8 to 8.2 kHz (-56). The respective source levels were usually 235 and 223 dB re 1 μPa, but the -53C briefly operated at an unstated but substantially higher source level. The unusual bathymetry and constricted channel where the strandings occurred were conducive to channeling sound. This, and the extended operations by multiple sonars, apparently prevented escape of the animals to the open sea. In addition to the strandings, there are reports that beaked whales were no longer present in the Providence Channel region after the event, suggesting that other beaked whales either abandoned the area or perhaps died at sea (Balcomb and Claridge 2001).

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24-25 September 2002 in the Canary Islands, where naval maneuvers were taking place. A recent paper concerning the Canary Islands stranding concluded that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, this might occur if they ascend unusually quickly when exposed to aversive sounds. Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2 to 10 kHz, generally with a relatively narrow bandwidth at any one time (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to hearing damage and, indirectly, mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As discussed earlier, there has been a recent (Sept. 2002) stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the L-DEO/NSF vessel R/V *Maurice Ewing* was underway in the general area (Malakoff 2002). The airgun array in use during that project was the *Ewing*'s 20-airgun 8490-in^3 array. This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys is inconclusive, and to this date is not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam bathymetric sonar at the same time but, as discussed elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multibeam sonar) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(h) Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound might include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in marine mammals exposed to sound from airgun arrays. However, there have been no direct studies of the potential for airgun pulses to elicit any of these effects. If any such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). However, there is essentially no information about the occurrence of noise-induced stress in marine mammals. Also, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced, as is the case for most two-dimensional seismic surveys.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at this frequency, the ensuing resonance could cause damage to the animal. There may also be a possibility that high sound levels could cause bubble formation in the blood of diving mammals that in turn could cause an air embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound.

As noted in the preceding subsection, a recent paper (Jepson et al. 2003) has suggested that cetaceans can at times be subject to decompression sickness. If so, this could be another mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death.

In summary, very little is known about the potential for seismic survey sounds to cause either auditory impairment or other non-auditory physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

Literature Cited

Literature mentioned in this Appendix is listed in the overall Literature Cited section earlier in this document.